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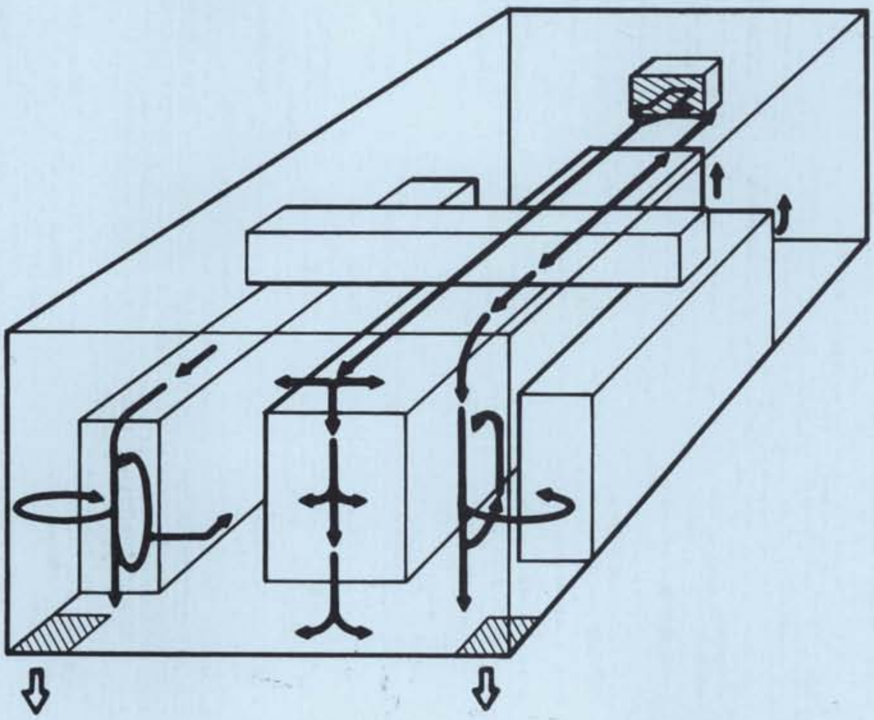
Health Physics Manual of Good Practices for the Prompt Detection of Airborne Plutonium in the Workplace



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July 1988

Prepared for the U.S. Department of Energy
Assistant Secretary for Environment, Safety, and Health
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HEALTH PHYSICS MANUAL OF GOOD PRACTICES FOR THE PROMPT DETECTION OF AIRBORNE PLUTONIUM IN THE WORKPLACE

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FOREWORD

This document, Health Physics Manual of Good Practices for the Prompt Detection of Airborne Plutonium in the Workplace, was prepared in response to recommendations from the attendees of the 1987 U.S. Department of Energy (DOE) Workshop on Workplace Aerosol Monitoring. It was apparent from discussions at the workshop that current national and international standards were heavily oriented toward duct and stack sampling and monitoring and did not adequately address the prompt detection of airborne contaminants in the workplace. The latter function is critical to prevent or at least minimize exposure of personnel at DOE facilities.

This document was prepared by a working group of technical experts and extensively reviewed within the DOE community. The group was requested to address plutonium as the initial airborne contaminant of concern due to the difficulty in detecting this radionuclide and its low allowable concentration (Derived Air Concentration) relative to other source terms present at DOE facilities. The guidance in this document incorporates applicable portions of existing standards and is intended to provide technically sound advice about prompt, cost-effective detection of airborne plutonium in the workplace.

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ABSTRACT

This manual provides guidance to U.S. Department of Energy (DOE) facilities on the prompt detection of airborne plutonium in the workplace.

Information is first given to aid in detection systems that will function effectively in various workplaces. Steps in designing a system are covered: its general requirements, the plotting of workplace sources of plutonium, and methods of determining workplace airflow patterns. Guidance is provided on the proper numbers and locations of probe sites, the orientation of probes for representative sampling, and the mixture of stationary and portable probes. Recommendations for delivery in sampling systems include examination of particle loss and self-absorption problems, methods of eliminating air leakage in the system, and optimization of decontamination capabilities. System flow rate, requirements in a collection medium, burial loss and pressure drop, and prudent frequency of renewing the collection medium are among air sampling considerations covered. After a discussion of controlling airflow and of vacuum sources and system backups, the checkpoints to ensure system reliability are listed.

The manual then discusses instrument specifications that provide correct airborne plutonium concentrations and reliably activate alarms. Focusing on the interrelationship of all components, essential factors in instrument reliability are addressed: the regulatory lower limit of detection and performance specifications of detectors and filters, maintenance and calibration requirements, and features of commonly used plutonium air-sampling instruments.

Finally, the manual advises on establishing a documentation program to archive and evaluate the performance of a plutonium air-sampling program.

EXECUTIVE SUMMARY

This manual provides guidance to U.S. Department of Energy (DOE) facilities on the prompt detection of airborne plutonium in the workplace. It was an outcome of the 1987 DOE Workshop on Workplace Aerosol Monitoring, which reviewed current standards of airborne contaminant monitoring. The objective of prompt detection is recognized as preventing or minimizing personnel exposures through air sampling. Plutonium was selected as the initial airborne contaminant of concern because of its low allowable airborne concentrations. The manual covers the topics of assessing workplaces for sources of airborne plutonium, devising and managing systems for monitoring exposures to workers, and documenting system and exposure data.

Because prompt detection of harmful contaminants is possible only with accurate workplace characterizations, it is necessary to carefully assess workplaces for plutonium sources and airflow in order to emplace monitoring systems designed for each particular environment. Assessments include determining the sources of plutonium and discovering the airflow patterns by means of a number of tested techniques (gaseous and smoke tracers, isostatic bubbles, fluorescent particle tracers, or ice nucleus or nonspecific aerosol particle tracers). It is then necessary to locate sampling equipment in areas that will be representative of airborne plutonium concentrations received by workers. Sample collection techniques must minimize particle losses, which occur by settling, static charge, or other means; sampling must also avoid particle buildup on the collecting medium, eliminate air in-leakage, and resist corrosion or other reactions with ambient atmosphere. To maintain system sensitivity, the flow rate and collection media must be suitably efficient. Requirements for airflow (both its control and measurement), vacuum source reserves, and emergency power supply are also important in system reliability. The testing of system components involves acceptance testing of new equipment as well as regular inspections, calibrations, and maintenance of existing equipment.

Various factors must also be considered for obtaining reliable instrument readings. Continuous air monitors (CAMs) must detect the lowest possible levels of collected radioactivity in the shortest possible time while also ensuring that spurious alarms are minimized. Besides the shielding, methods of alarm, and reliability of equipment, the factors affecting the levels of detection and spurious alarms include the efficiency of detector and sampling units, volumetric rate of air sampled, and methods of discriminating types of radiation. The commonly used plutonium air-sampling instruments must be maintained and calibrated according to standards, preferably by a 12-step calibration procedure.

Like the maintenance and calibration of instruments, documentation is needed for evaluating the system's performance. Documentation is required at least of sampler inlet studies, sampler design and selection, data collected, calibrations and field response adjustments, and changes in the sampling systems or environments.

The practices designated as essential for the proper functioning of a system/program for prompt detection of airborne plutonium in the workplace are as follows:

- A description of all the requirements and characteristics of the system shall be formalized in a written statement.
- The lower level of detection shall be the activity equivalent to 8 DAC-h averaged over a time frame of 1 min or longer.
- A local data base of sources and characteristics of airborne plutonium for specific work areas shall be maintained.
- The airflow pattern within the workplace to be monitored shall be determined prior to the placement of sampling points and the activation of prompt detection systems.
- The number and location of sample extraction points shall provide adequate coverage to protect workers from exposure to challenges exceeding 8 DAC-h.
- The transport system shall be designed to minimize particle losses.

- The transport system shall be designed to avoid localized or preferential areas of particulate buildup on the collection medium.
- The transport system between sample intake and delivery to the collecting medium shall be designed to limit air in-leakage to less than 10%.
- The transport system shall be designed to resist corrosion or other possible reactions with the atmosphere sampled and shall facilitate decontamination.
- Air sampling records shall include references to approved operating procedures, including identification by procedure number, revision and modification numbers, date, title, and author.
- Written records shall be legible and retrievable.
- Detection capabilities shall be maximized by minimizing the burial losses in filter media and self absorption from dust loading.
- The sample-to-detector distance shall be minimized, considering sample collection requirements.
- Discrimination for reducing the contribution of naturally occurring alpha emitters shall be provided.
- Spurious alarms shall be minimized.
- CAM maintenance and calibration programs shall be developed and followed to address mechanical and electrical components.
- Periodic performance testing and calibration shall be conducted at least annually. Results shall be documented.

ACKNOWLEDGMENTS

The working group acknowledges the contributions of the technical and support staff at Pacific Northwest Laboratory who have read, reviewed, and produced this guide: Eva Hickey, who was task leader; Judson Kenoyer, who supplied review and technical guidance; Ginny Leslie and Jim Weber, who edited the drafts; and Toni Jewell, who provided word processing support. They also acknowledge the help of numerous staff members at the U.S. Department of Energy and at the authors' various organizations who discussed and reviewed the drafts.

CONTENTS

FIGURES

TABLES

GLOSSARY

Activity Median Aerodynamic Diameter (AMAD)	The aerodynamic diameter for a lognormal distribution of diameters, where half the activity present is associated with particles less than, and half of the activity is associated with particles greater than, the stated diameter.
Activity Median Diameter (AMD)	The diameter (in any stated units) for a lognormal distribution of particles, where half the activity present is associated with particles less than, and half the activity is associated with particles greater than, the stated size.
Administrative Action Level	The airborne concentration of a radionuclide requiring some action by personnel (e.g. , donning respiratory protection devices, evacuation of workplace).
Aerodynamic Diameter (AD)	The diameter of a sphere that exhibits the same aerodynamic behavior (commonly the terminal velocity) as the particle.
Aerodynamic Equivalent Diameter (AED)	The diameter of a unit density sphere that exhibits the same aerodynamic behavior (commonly the terminal velocity) as the particle.
Airborne Radionuclides	Radionuclides suspended and carried in the air within a workplace.
Annual Limits on Intake (ALI)	A secondary limit on the annual quantity of a radionuclide, designed to meet the basic limit for occupational exposure recommended by the ICRP.
"Blunt" Sampler	An inlet to a sampler that has a large flat area (generally many times the area of the opening) surrounding the opening.

Breathing Zone	Commonly used designation for samples collected at levels in the workplace that are believed to approximate the height that air is inhaled by personnel (normally 5 ft to 6 ft above the floor).
Continuous Air Monitor (CAM)	Instrument that continuously samples and measures the level of an airborne radionuclide.
Count Median Aerodynamic Diameter (CMAD)	The diameter (in units of aerodynamic diameters) when half the number of particles present are greater than or less than the stated diameter.
Count Median Diameter (CMD)	The diameter (generally in units of projected diameters) when half the number of particles present are greater than or less than the stated diameter.
Cyclones	An inertial, particle separation device without moving parts. Particles are separated from the carrier gas by converting the inlet velocity into a double vortex confined within a cylinder.
Derived Air Concentration (DAC)	The airborne concentration that equals the Annual Limits on Intake (ALI) on the assumption of a 50-wk, 40-h/wk exposure. Equal to the Derived Airborne Concentration found in ICRP Publication 30 converted to conventional units of curies.
Fixed Sampler	A sampler (probe) at a fixed location in the workplace.
ICRP	International Commission on Radiological Protection.
Impactor	A device that samples aerosol particles by size increments onto collector surfaces.
Isoaxial	In the same axis as (parallel to) the axis of major flow. For sample extraction purposes, the opening (inlet) of the extraction probe should be perpendicular (at right angles) to the dominant flow direction of the stream sampled.

Isokinetic Sampling (with the same motion)	A condition that prevails when the velocity of air entering a sampling probe or collector held in the air stream is identical to the velocity and axis of flow of the air stream being sampled at that point.
Mass Median Diameter (MMD)	The diameter (in any units stated) for a lognormal distribution of diameters, where half the mass present is associated with particles less than and half the mass associated with particles greater than, the stated size.
Measurement	The accurate quantification of radionuclides collected or sampled.
Minimum Level of Detectability (MLD)	The smallest concentration of a radionuclide measurable at a given confidence level, in a stated period of time, at a given flow rate, and under specific background radiation conditions.
Monitoring	The accurate quantification of a "representative" sample of airborne radionuclides by the continuous generation of a signal representing the radionuclide of interest.
Portable Sampler	Instrument measuring the airborne concentrations of radionuclides, designed to be moved from area to area.
"Representative Sampling"	The obtaining of airborne material or a fraction of airborne material (e.g., the "respirable" fraction of airborne particles) for quantification of their characteristics.
"Respirable" Size Fraction	The fraction of airborne particles that can be inhaled, transported through the human respiratory system, and deposited in the lungs. Conventionally, the conservative estimate of all particles 10 μm AED and less is considered the "respirable" fraction.

Projected Diameter	The circle equivalent in diameter to the area projected by the particle at the plane of viewing (a two-dimensional measurement).
SAAM	Selective alpha air monitor. Specific types of alpha-activity CAMs.
Sampling	The act of obtaining a fraction of material to represent the whole.
W Class	A class of inhaled material with clearance half times from the pulmonary region of the lungs in the range of 10 to 100 days.
WOTAM	Workplace transuranic air monitor. Specific types of alpha-activity CAMs.
Y Class	A class of inhaled material with clearance half times from the pulmonary region of the lungs in excess of 100 days.

1.0 INTRODUCTION

This manual provides guidance to U.S. Department of Energy (DOE) facilities on the prompt detection of airborne plutonium within the workplace. To introduce the topic, Section 1.0 provides background in the relevant orders and standards, the objectives of prompt detection, a key to the terminology used in this manual, and its applicability to warning systems for other airborne particulates.

1.1 APPLICABLE DOCUMENTS

A draft DOE order (5480.11, 4-5-88) provides specific regulatory limits on airborne plutonium, and more general goals are suggested in several relevant standards.

1.1.1 DOE Draft Order 5480.11 (8-3-87)

The regulation governing this area is Draft DOE 5480.11 (4-5-88), Radiation Protection for Occupational Workers. The purpose of the Order is "To establish radiation protection standards and program requirements for the Department of Energy and Department of Energy contractor operations with respect to protection of the Worker." The Order provides Derived Air Concentration (DAC) values for plutonium in air (Attachment 1 in Order) as a function of lung clearance rate classes. For ^{239}Pu, the DAC for W-class is 2×10^{-12} µCi/ml and 6×10^{-12} µCi/ml for Y-class.

The Order requires air monitoring in areas that have the potential to exceed 10% of any DAC. The Order recommends that the monitors be capable of measuring one DAC when averaged over 8 h (8 DAC-h). The Order further states, "Ambient air monitoring systems shall be placed in strategic locations to detect and evaluate airborne contamination at work locations."

The policy of the DOE, the Order states, is "to keep all radiation exposures within the limits and as low as reasonably achievable."

1.1.2 National and International Standards

The current standards [American National Standards Institute (ANSI) N13.1-1969; International Standardization Organization (ISO) 1975; International Electrochemical Commission (IEC) 1983a, 1983b] are heavily oriented toward duct and stack sampling and monitoring. None provides a detailed discussion of workplace airborne contaminants, such as plutonium. The portion in ANSI N13.1-1969 that is devoted to worker protection (Section 4.2.1.1, "Sampling in a Zone Occupied by Workers") is oriented toward exposure assessment. Although many of the concepts and principles of sampling found in the guide are applicable to the prompt detection of airborne contaminants, they address the problem generally. The pertinent sections in the proposed revised ANSI standard[a] (in Section 8.1.1, "Sampling During Routine Operations" and Section 8.1.2, "Sampling for Emergency Response") are also directed toward exposure assessment. Section 8.1.1 is more informative than Section 8.1.2 for the purposes of prompt detection of airborne materials. The ISO Guide contains essentially the same information as the ANSI Guide. The two IEC standards are oriented toward electronic instrumentation used for effluent monitoring. A third ANSI standard, ANSI N317-1980, contains specifications for the operating characteristics of continuous air monitors (CAMs) and contamination survey instruments for plutonium, but it does not specify performance criteria for the extraction, transport, and collection for the CAM.

1.2 OBJECTIVE AND SCOPE

The objective of prompt detection is to prevent or at least minimize the exposure of personnel. To achieve this goal, the system must sample the air that reaches personnel in the workplace and detect airborne concentrations at a level that could result in significant exposure. Rapid and reliable detection of airborne plutonium, rather than a high level of accuracy and precision required for some other airborne monitoring systems, is emphasized for the types of systems described in this document. Indeed, plutonium was selected as the initial airborne contaminant of concern in DOE facilities because of its low allowable airborne concentrations [Derived Air Concentration (DAC)].

(a) Draft ANSI N13.1. 1969. Guide to Air Sampling for the Control of Occupational Exposures to Radioactive Materials at Nuclear Facilities.

Those responsible for providing a system for the rapid and reliable detection of airborne plutonium must consider the following areas of concern in evaluating monitoring systems and working environments:

- the source and characteristics of the airborne plutonium released to the workplace
- the airflow patterns and airborne transport of plutonium in the workplace
- the location of personnel within the workplace during various processing operations
- the location at which the airborne plutonium sample should be intercepted to be representative of material inhaled by workers
- the ability of the system to transport an undistorted sample of the airborne plutonium to the collection medium or measurement device
- the collection and retention efficiency of the collection medium, if used, and the characteristics of the collection system design
- the efficiency of the measurement device in measuring the plutonium collected
- the differentiation of plutonium from other materials present
- the accuracy and reliability required of the system
- the nature and amount of documentation necessary to substantiate decisions made about various aspects of the detection system and to record tests determining its accuracy and reliability
- other objectives or characteristics stated for the system that could affect the rapid detection of airborne plutonium (e.g., the level of airborne plutonium that must be detected).

Each of the following sections contains a detailed discussion of the characteristics cited above, which are the basis for the guidance provided in this report. Section 2.0, Information to Assist in the Selection of System Characteristics and Requirements, discusses the aspects of the workplace and sampling requirements that should be thoroughly characterized prior to design and specification of sampling. Sample Extraction, Section 3.0, provides guidance on the characteristics of workplace sample sites, which determine the number, orientation, and placement of sample extraction probes. Guidance on the choice of sample delivery and collection systems for prompt airborne plutonium detection is provided in Section 4.0. Section 5.0, Instrumentation, provides guidance on the capabilities and operating characteristics of instruments to measure the plutonium collected. In Section 6.0, Documentation, the collection and maintenance of various documents and data in a central data base is recommended to substantiate the validity of systems used for the prompt detection of airborne plutonium in the workplace.

The specifications for and the current availability of a11 instruments for prompt detection of airborne plutonium are beyond the scope of this document. However, this document provides guidance on commonly used sampling instruments and on where to locate airborne-plutonium monitors to ensure the early detection of airborne concentrations. The working group assumes that these early detection monitors are a requirement of an overall worker protection system. Other requirements, such as quality assurance, are not discussed here but are assumed to be part of the overall protection system.

Certainly, it is not possible to foresee all situations that may develop at various locations. Thus, the authors encourage a careful assessment of situations arising at specific sites when applying the guidance.

1.3 TERMINOLOGY

The word shall is used in this manual to indicate a practice or equipment specification that is considered to be essential to the proper functioning of a prompt detection system for airborne plutonium in the workplace. The word should is used to denote practices or specifications that are not essential in every case but should receive consideration.

1.4 APPLICABILITY TO OTHER WORKPLACE MONITORING SYSTEMS

Although the practices and specification in this manual are directed specifically toward prompt detection systems, they are generally applicable to other workplace monitoring systems for airborne particulate materials. The applicability of isokinetic sampling practices for airborne particulate materials in the workplace is questionable. Application of the isokinetic principles requires knowledge of the direction and velocity of the air stream in which the particulate materials are carried. Determining these parameters is not a trivial task in the complex arrangements often found in processing facilities. The definition of airflow patterns within the workplace recommended in this manual will partially fulfill the requirement. Most of the particle transport and collection system practices are directly applicable to all monitoring systems for airborne particulate materials. The practices and specification with regard to instrumentation are applicable only to systems for alpha-emitting plutonium although some may be worth considering for other radionuclides.

2.0 INFORMATION TO ASSIST IN SELECTION OF SYSTEM CHARACTERISTICS AND REQUIREMENTS

Before the characteristics and performance requirements can be established for a system for the prompt detection of airborne plutonium in the workplace, information on various aspects of the system and workplace should be collected. A description of all the requirements and characteristics of the system should be formalized in a written statement. Guidance on writing system requirements is provided in Section 2.1. An analysis shall be performed of the three major variables affecting the transport of contaminants: the plutonium particle size, the composition of the plutonium aerosol, and the airflow patterns in the facility. The probable sources and characteristics of the airborne plutonium released (e.g., its chemical compound and its particle-size distribution) are discussed in Section 2.2. The airflow patterns within the workplace that could transport the airborne plutonium to personnel are covered in Section 2.3.

2.1 FORMALIZATION OF THE REQUIREMENTS OF THE PROMPT DETECTION SYSTEM

There are three considerations in determining the requirements for a prompt-detection system for plutonium: establishing the objectives of a system, deciding upon a level of detection, and choosing a type of detection instrument.

2.1.1 Written Objectives and Records of Performance

To focus the effort on the essential items, to ensure that major considerations are not missed, and to provide documentation, a written statement of the objectives of a system for prompt detection of plutonium shall be prepared. Written objectives allow the results of tests or studies to be compared to their original purposes, to ascertain whether the objectives were achieved. The objectives may be to retrofit a prompt-detection system for an existing workplace, to assist in designing a system for a new facility, or to test or upgrade a currently operating system. Requirements for achieving various objectives might be radically different and will dictate different levels of effort and equipment.

It is also important to document the performance and characteristics of the detection instruments: their initial calibrations, the periodic checks of their performance, the data that substantiate their reliability, and even the information leading to a decision to select one or another instrument.

Detailed guidance on performance documentation is provided in Section 6.0.

2.1.2 Level of Detection

For systems monitoring airborne contamination within the workplace, the lower level of detection recommended in the draft DOE Order as a performance spec for instruments is "one DAC averaged over 8 h (8 DAC-h)." However, DOE policy is to avoid any internal exposures.

To prevent or minimize exposure of occupational workers to this level of radioactivity, the systems for prompt detection shall detect and alarm when the workers are challenged by the equivalent level of airborne activity over the same time frame. Thus, the lower limit of detection for prompt detecting systems shall detect one DAC averaged over 8 h, 8-h DAC averaged over 1 h, 16 DAC over 30 min, 32 DAC in 15 min, 96 DAC in 5 min, and so on.

The lower limit of detection for a prompt detection system is influenced by the many factors covered in this manual. Most measuring devices and system parameters have limitations, and the principal variable to increase the lower limit of detection for a system available to the user is the sampling flow rate. Practicality also limits the sampling flow rate, but the range is relatively large.

If a measuring device (instrument) has a lower limit of detection of 1 DAC averaged over 8 h (8 DAC-h) at a flow rate of 1 cfm, the instrument can detect (for Y-class material) 6 E-12 μCi/ml x 2.832 E+4 ml/ft^3 x 60 min/h x 8 h = 8 E-5 μCi. There are 2.22 E+6 dpm/μCi. Therefore, the instrument can detect the presence of 181 dpm. The same activity could be collected and measured in one-tenth the time (48 min) at a sampling rate of 10 cfm. Thus, for the purposes of prompt detection of airborne contamination, higher sampling rates are desired.

2.1.3 Type of Detection Instruments

Another consideration is the type of detection instrument used. Although highly accurate measurements are not essential for prompt detection systems, the best available technology for these purposes should be considered. These devices must be reliable because personnel protection is dependent upon their performance. Furthermore, they shall be calibrated and the calibrations periodically verified. The initial calibration and periodic checks of the devices, plus information to substantiate their reliability, shall be documented.

In some instruments, a form of inertial separation is used to separate the airborne natural radionuclides (radon-thoron and their decay products) to prevent interference with the plutonium measurements. Other instruments have electronic systems to separate the two counting rates.

Depending upon the lower limits of detection of the instruments, various airflows may be required to achieve the detection limit for the system. The airflow requirements will be a consideration in the air mover and airflow measurement devices to be used. The airflow requirements will also determine the pipe/duct size needed to maintain the air velocity within the transfer lines for the undistorted transfer of airborne plutonium particles. Because the need to maintain isokinetic conditions during prompt sampling is not critical, the inlet/extraction probe is not affected by the airflow. Nevertheless, efforts should be made to retain as many good sampling practices as possible, as long as they do not require an increase in the level of effort or compromise rapid, reliable detection.

Specifications of instruments appropriate to prompt detection of airborne plutonium are discussed in more detail in Section 5.0.

2.2 DETERMINATION OF THE CHARACTERISTICS OF POTENTIAL SOURCES OF AIRBORNE PLUTONIUM

Both the potential sources and the characteristics of airborne plutonium in the specific workplace are needed to properly determine the capabilities required in a system. A local data base of the sources and characteristics of airborne plutonium for specific work areas shall be maintained for this purpose. All the information on the characterization of after-the-fact evaluations of airborne releases that have occurred in the workplace shall be included in the data base. Information on potential sources is especially important for placing sample-extraction sites because such a site should be located between the source and the personnel at risk. Thus, studies of workplace environments should characterize airborne plutonium in glove box areas, areas in which processing is occurring, or areas in which there are effluent gases.

Besides the potential of airborne plutonium, the nature of the plutonium particles should also be characterized. The size of plutonium particles and that of the particles hosting them (if any) should be sought. The data in these studies should give the particle size in terms of the aerodynamic equivalent diameter (AED) to predict fluid dynamic behavior of the particles.

2.3 DETERMINATION AND ANALYSIS OF AIRFLOW PATTERNS

Airflow patterns are one major variable in sampler response to potential plutonium particle releases in a given location (the others, noted above, are particle-size distribution and composition of aerosol). Airflow patterns within the workplace to be monitored shall be determined prior to the placement of sampling points and the activation of prompt detection systems. For existing and new facilities, this document provides information on where to locate airborne plutonium particle monitors to give the earliest possible warning of a release. (See Section 3.0 for a detailed discussion.) This guidance is directed toward upgrading existing systems as DOE regulations become more stringent. The guidance may also be of value as a basis for experimental studies (e.g., mock-ups) of proposed facilities to aid in design criteria.

Whether for upgrading or projective studies, airflow patterns in a room shall be defined before an effective prompt-warning system can be established. Airflow patterns shall be determined for a reasonable range of ventilating rates; the relationship of dispersion pattern and particle size, as well as the speed of contaminant spread, should also be established. The condition of variables existent at the time of testing must be well understood and the testing repeated for conditions of significant change. Use of doorways and hoods, automatic dampers, changing thermal sources, equipment and layout changes, and rebalance of ventilation are examples of changing conditions that can significantly alter airflow patterns. Periodic confirmation testing is recommended.

Airflow studies should be related to potential sources of contamination, e.g., work areas and associated equipment. Tests should define the airflow past the potential sources to the known location of personnel. Furthermore, information on the potential dilution of the pollutant plume during transport is desirable. These are site-specific questions and draw upon past experience in particular locations. Such site-specific information is needed to direct monitoring studies to potential problem areas, so that air samplers are properly positioned.

The following sections review the commonly available techniques for discovering airflow patterns. This overview includes descriptions of gaseous tracers, such as helium and sulfur hexafluoride (SF_6), smoke tracers and isostatic bubbles, fluorescent particle tracers, ice nucleus particle tracers, and nonspecific aerosol particle tracers.

2.3.1 Gaseous Tracers

Sulfur hexafluoride (SF_6) is a widely used gaseous tracer, especially for studies of building ventilation. The recirculation of building exhaust into building intakes is often of concern (Barnett 1983). Also, clearance rates for radon in homes have been studied with SF_6 (Nazaroff 1983). Sulfur hexafluoride is detected by gas chromotography or electron capture devices. These devices are just becoming available for routine use (Benner 1984).

The French Atomic Energy Commission [Commissariat 'a 1'Energie Atomique (CEA)] uses both SF_6 and helium for acceptance tests of new facilities and verification of existing ones (CEA 1984). The CEA has published results from flow-pattern studies in plutonium-processing areas with helium as a tracer (Vavasseur 1985). Vavasseur studied both puff and continuous helium tracer gas releases into a work area. This was supplemented by the release of two sizes of fluorescent particles (FPs) to compare the transport of gaseous and particulate tracers.

2.3.2 Smoke Tracers and Isostatic Bubbles

Smoke bombs or candles have been used widely as air tracers in work areas. However, these devices release heat and lift the smoke, thereby distorting normal flow patterns. "Cold smoke" or fog can be generated by atomizing a heated light oil or with small aspirated smoke tubes. Such smoke is not as dense as smoke from a smoke bomb and does not seriously interfere with work. In tests at the Rocky Flats Plant, a 5-min smoke bomb filled a large room in about 2 min. This was determined by photoelectric smoke detectors set to alarm at 2% obscuration.[a] At the same time, the spread of the smoke was recorded with a video camera. Small smoke candles can also be used to trace airflow in one glove box bay at a time.

A generator for isostatic bubbles, which float in the air with zero buoyancy, was developed by the CEA. The bubbles, which are filled with air and a small percentage of helium, can stay afloat for hours (CEA 1984). These are useful for detecting flow direction. More recently, the Los Alamos National Laboratory developed a similar device. Helium-filled balloons proved most effective in following airflow patterns.[b] Video taping is the best method for data recording.

2.3.3 Fluorescent Particle Tracers

These aerosol tracers have the advantage of more closely simulating the inertial properties of plutonium-carrying aerosols than do gaseous tracers. A solution of fluorescein or uranine dye (CEA 1984), which is nebulized and dried, is a convenient source of tracer particles that can be detected by fluorescent spectroscopy. However, special care should be taken with tests using fluorescent dyes as tracers because the presence of other compounds acting as quenchers of the fluoresence result in spurious measurements that can invalidate test results.

(a) J. Koffer, Rocky Flats Plant, personal communication.
(b) Draft. Pickering, P. L., et al. 1987. "Test Ventilation with Smoke, Bubbles, and Balloons."

Scripsick et al. (1979) simulated the release of plutonium particles with fluorescein in a plutonium-processing area. This included computer simulation with the SOLA Code (Hirt 1978) to verify the observed flow patterns, which were also tested with smoke bombs. In the test room the air entered at the ceiling on one side and left through two floor exhausts on the opposite side. Eight fixed-filter samplers were used to collect the tracer at the glove boxes, and the four continuous air monitors (CAMs) in the room were also used as samplers. In this situation the air tended to flow along the ceiling so that part of it was exhausted, but the rest recirculated below the level of the glove boxes. Tracer was found throughout the room for all 20 sampling points, which were at a height of 1.4 m. These integrated-filter samples precluded knowledge of variations with time at the sample points.

The computer analysis was used to improve the clearance of particles from the room by modifying the ventilating system. Similar tests were run in another room with a ventilating inlet running down the center of the room and exhausts in each corner. Greater variations in concentration were found in this situation. Finally, calculations were made to determine the release detection probability for given sampler locations. This led to the optimization of sampler locations and number.

Another particle tracer is aerosol ZnS, which can be detected by microscopic counting under ultraviolet light illumination. The tracer particles are collected on filters for analysis. However, the repeated use of these particles may lead to biased data resulting from resuspension of deposited particles. Vavasseur (1985) used a combination of helium tracer gas and ZnS tracer particles to determine flow patterns and distribution of particles released to a workplace (see Section 2.3.1 on gaseous tracers).

2.3.4 Ice Nucleus Particle Tracer

Ice nuclei (IN) are particles that nucleate ice crystals in supercooled clouds. The IN concentrations in the atmosphere are very low. Only a few chemicals, such as silver iodide and phloroglucinol, nucleate ice crystals efficiently. These chemicals are released in three ways: by vaporization-condensation as fine smoke particles in the 0.02- to 0.5-μm range, by atomization of solutions and subsequent droplet evaporation as particles in the 0.2- to 5-μm range, and by aerosolization of powders as particles in the 3- to 20-μm range.

A single-particle, real-time detector is used to track the IN particles (Langer 1987). The detector consists of a 10-L cloud chamber and associated refrigeration equipment, weighing a total of 130 lb (59.1 kg). The sensitivity of the tracer is very high (the material can be detected in open air over distances of 50 miles). However, the bulky equipment makes multipoint sampling impractical, unless grab samples are collected with a syringe. Although this procedure was used in two plutonium areas with useful results, multipoint sampling was deemed essential by the researchers for systematic flow-pattern studies. The same conclusion was also reached by French workers studying ventilation in plutonium areas (CEA 1984). Therefore, a laser particle counter (LPC) procedure, described in Section 2.3.5, is being adapted for work at the Rocky Flats Plant.

The IN procedure provides real-time dispersion data and allows for the study of tracer buildup to its final concentration, as well as clearance of the tracer. Both buildup and clearance have been found to take 10 to 25 min, even in one large processing area, depending on tracer release and sampler location and air change rate (Langer 1987). The tracer was found throughout the room and mixed rather uniformly from floor to ceiling. Very definite flow patterns were also evident, and these persisted over the weeks of testing. The effects of opening doors were also evident. The use of perforated ceiling panels in one module did not produce a laminar downflow effect as expected. Tracer concentration was a direct function of air change rate in one room but not in the other. Time to first response (detection) did not depend on air rate change.

2.3.5 Nonspecific Aerosol Particle Tracer

A nonspecific aerosol tracer is useful because instrumentation for counting aerosol particles in general by optical means is readily available and relatively inexpensive. Moreover, it provides data in real time, the detectors can be multiplexed, and the data output can be routinely computerized.

A laser particle counter (LPC) system has been used with two particle-size ranges, >0.5 μm and >5.0 μm, to study flow patterns (Langer 1987). Commercial software and a multiplexer system to handle data from up to 64 detectors simultaneously are available. Other sensors, such as air velocity probes, can be incorporated into the system. A simple pneumatic atomizer produced solid tracer particles from the evaporation of sugar solution droplets.

The tracer aerosol generator is one of the critical items for a successful aerosol tracer study. A generator is required that produces a narrow size distribution, so its output is easily discernible above background aerosol particles in the same range. Vibrating orifice atomizers are available to produce nearly monodisperse particles in the 0.5- to 40-μm range in high concentrations. A sugar solution or commercial syrup was used to avoid any health or corrosion problems. The other option was to atomize an inert liquid, such as corn oil or synthetic diffusion pump oil, to produce a coarser mist.

With two LPCs, the feasibility of this procedure could be demonstrated only on a local scale, i.e., for only two to three glove box bays instead of a complete room. Figures 1 and 2 present summary plots for two counters and size ranges: one LPC (LPC1) was 30 ft from the source, while a second (LPC2) was at a distance of 12 ft. The relatively constant concentration should be noted for particles >0.5 μm (Figure 1). This has been a consistent pattern and probably reflects the aged background aerosol resulting from Denver pollution. The concentration of particles >5.0 μm (Figure 2) is more variable. These particles are of local origin, many from the room itself, and their concentration is two orders of magnitude less than the >0.5-μm range. The time span during which the tracer was released (Langer 1987) is shown in each figure.

The time for the tracer to reach the LCPs is of interest because it is one of the variables that controls the alarm time for plutonium. The time for the first response was about 2 min for either detector. To reach equilibrium tracer concentration after tracer arrival for the >0.5-μm particles took 3 min for LPC2 (the LPC nearest the source) while LPC1 required 6 min. Three minutes were required for particles >5.0 μm to reach LPC2, but no estimate could be made for LPC1 because not enough tracer particles >5.0 μm reached the

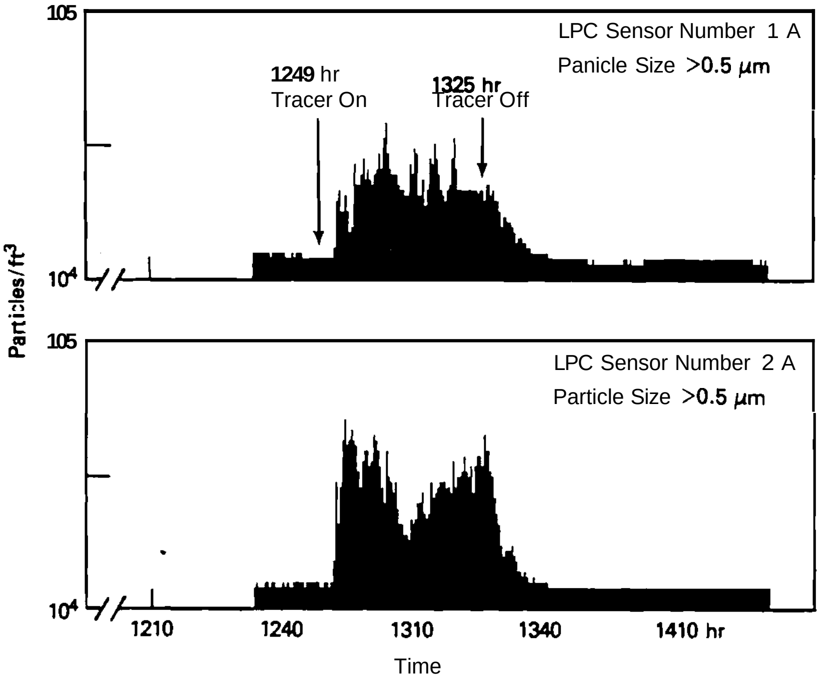

FIGURE 1. Exploratory Air Tracer Test - Detection of A71 Particles >0.5 μm (linear scale)

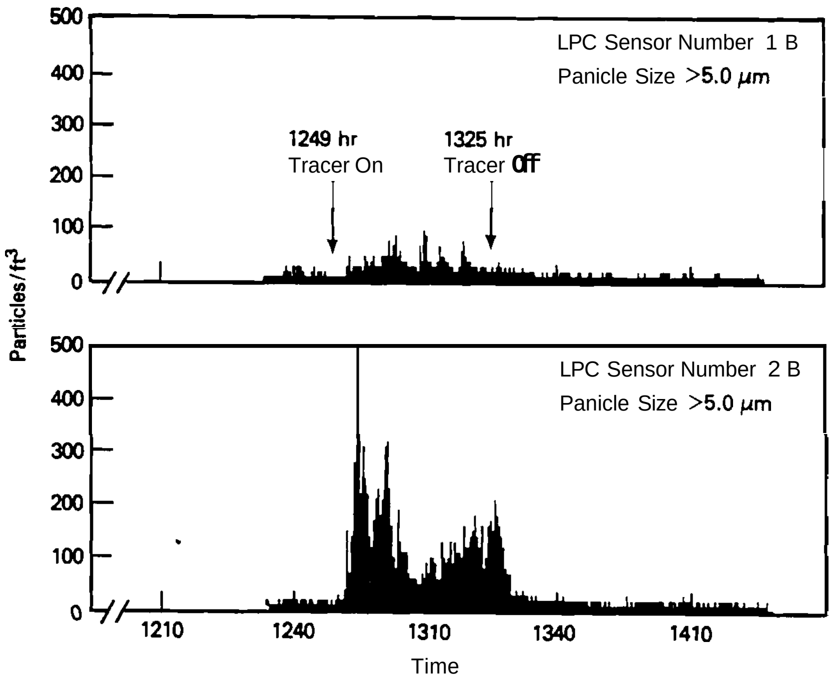

FIGURE 2. Exploratory Air Tracer Test - Detection of All Particles >5.0 μm (linear scale)

detector. Evidently, the larger particles settled out before reaching LPC1. This is an important observation.

This means that large particles, which would be expected to carry most of the activity spreading from a leak, will contaminate the room surfaces. However, at some distance from the leak, personnel will not be affected as much. This sedimentation of particles also suggests that the response of the Selective Alpha Air Monitor [SAAM (the type of CAM used in the Rocky Flats Plant facility)] will be poor unless the SAAM is close by. This result supports the contention that a tracer should be particulate and include larger particles (i.e., a gaseous tracer alone could be misleading.)

The decay time to background levels after the tracer generator is shut off is of importance. The time was about 13 min for either detector for the >0.5-µm particles. For the larger particles the decay was about 8 min at LPC2 and not discernible at LPC1. Again, settling of the large particles is evident.

The data given above were in good agreement with previous IN tracer work at the same location with submicron particles (Langer 1987), except this tracer did not allow the study of particle inertial effects.

2.3.6 Summary of Airflow Tracer Techniques

Gaseous tracers do not address inertial effects exhibited by larger aerosol particles. A gaseous tracer is not practical when filtered recirculation is used in a ventilating system because the gas is not removed and would not reflect the behavior of airborne particulate materials.

Particulate or aerosol tracers, which can take a number of forms, are an obvious alternative. For qualitative work, visual observation of a smoke tracer has the obvious advantage of simplicity and economy. However, smoke interferes with ongoing work, and the smoke generator may cause local convection that distorts normal flow patterns. Instead of smoke, isostatic (neutral buoyancy) bubbles provide very useful visual flow direction and velocity data. A system of anemometers can measure flow velocities directly, but routine determination of flow direction at low velocities is not currently a readily available technology. Fluorescent particles provide a unique signature in the presence of background aerosols. The introduction of an ice nucleus aerosol provides another unique marker. A nonspecific aerosol can be released as a tracer, but its concentration must be high enough to be detected above the background aerosol.

Some of the principal advantages and disadvantages of the major airflow tracer techniques discussed are shown in Table 1.

TABLE 1. Comparison of Techniques to Determine Airflow Patterns Within the Workplace

Technique	Advantage	Disadvantage
Smoke bombs/candles	Required equipment is readily available Provides visible evidence of airflow	Semiquantitative Can limit visibility, cannot perform during operations May leave objectionable residue May generate thermal plumes
Isostatic bubbles	Visible More persistent than smoke	Semiquantitative Objectionable during operations Can leave undesirable residue
Tracer gas	Quantitative for noncondensible gases, reasonable facsimile for particles <2 μm	Can require large array of detectors Choice of tracer gases limited
Tracer aerosols	Can be quantitative	Complex requirement, choice of tracers limited Large array of gas and particle detectors, as well as velocity and temperature detectors, are needed

3.0 SAMPLE EXTRACTION

The importance of proper location of sample extraction probes for prompt detection of airborne plutonium cannot be overstated. Proper placement of sampling probes requires considerable experience in operating facilities. In addition to discussing the location and numbers of extraction sites, this section provides guidance on sample probe design and orientation. The need for fixed and portable extraction probes is also addressed.

3.1 PROBE LOCATIONS AND NUMBER

The location and number of extraction sites depend on the degree of coverage desired or needed to warn personnel of airborne contamination. Physical restraints and economic considerations likewise may limit the location and number of extraction probes. The number and location of sample extraction points shall provide adequate coverage to protect workers from exposures to challenges exceeding 8 DAC-h. Ideally, each work station where routine operations with potential for releasing plutonium are carried out would have an extraction probe. Because ideal monitoring arrangements often do not exist and complete mixing of room air rarely occurs, the placement of sample probes or the CAMs should represent a combination of ventilation flow data and operating experience. Many facilities tackle this problem by using fixed samplers at or in the room exhaust ducts and a mobile CAM placed close to a particular job with high airborne contamination potential. When portable units are not used (due to space, noise, or other limitations), extraction probes, positioned so as not to interfere with the worker or work, may be mounted on or near glove boxes, where the highest potential for leaks exists. Such mounted units, which could serve as the "primary warning system," should be supplemented with sampling of room exhaust if experience and airflow data support this arrangement.

In locating sampler inlets at or in exhaust ducts with an area greater than 1 ft^2, consideration should be given to providing more than one sample inlet in order to ensure representative sampling. If ventilation pattern studies confirm good air mixing before reaching the exhaust port, then the central location of one inlet may be justified. If localized airflow patterns from potential release sources are observed at the exhaust port, then more than one sample inlet should be considered, with manifolding of the several inlets for delivery to the detector. Guidance from Appendix A3 in ANSI N 13.1-1969 (ANSI 1969) may be useful in arriving at the desired number of sample inlets and their locations.

Downflow ventilation patterns (supply from ceiling, exhausts near floor) with demonstrated clearance of airborne contamination may call for sampling probes in locations below the workers' breathing zone to provide the earliest warning.

No sampling device should be positioned where it "overcomes" the containment barrier exhaust, thereby causing an airborne contamination reversal.

If justified by documented studies, the user may employ other sample probe arrangements.

3.2 PROBE ORIENTATION

Sample probe orientation for warning systems depends on the type of sampler/monitor used. Where the sample probe or pipe leads to a collector/ detector system, the opening of the probe should optimally be facing toward the source of contamination. The probe should be rigid and tapered on the outer edge to extract aerosols without significant perturbation of the flow. Blunt samplers can result in the loss of particles because of turbulence at the opening (Mark, Vincent, and Witherspoon 1982; Vincent, Emmett, and Mark 1985).

Although isokinetic sampling principles are not strictly applicable to air monitoring in the workplace, it is still desirable to avoid particle discrimination mechanisms at the sample entry point.

Some facilities use a close-coupled sampler/collector/detector combination that does not meet the probe design considerations of ANSI N 13.1-1969 (ANSI 1969) but may prove to be the best warning device. These collectors should be evaluated for aerodynamics to optimize particle collections.

3.3 FIXED VERSUS PORTABLE EXTRACTION PROBES

Whether extraction probes are fixed or portable, the user should observe as many good practices of aerosol sampling as possible without compromising the intent of the early detection system. Because of the mobility of workers, a combination of fixed and portable systems will likely be needed to monitor the working environment. While fixed probes may provide the simpler arrangement, the need for flexible, unobtrusive probes (whether attached to a portable CAM or a remote monitor linked to a central vacuum system) may make the ANSI N13.1 guidance difficult to follow.

4.0 SAMPLE DELIVERY AND COLLECTION SYSTEMS

Every aspect of the overall rapid detection system must support the broad objective, which is to optimize the collection, detection, evaluation, and documentation of significant amounts of plutonium particles in the workplace. The portion of the system that encompasses the mechanisms for sample transport to the collector, as well as the collector itself, must be as carefully designed, operated, maintained, and calibrated as any other portion of the overall system.

This section discusses the guidelines that are considered important to optimizing both the delivery of particles to the sample collector and the collection of those particles for presentation to the detector. Standard approaches are also recommended to meet the guidelines.

The discussion that follows is presented in five major categories:

- guidelines for sample delivery
- guidelines for sample collection
- airflow control and measurement requirements
- vacuum source and backup requirements
- reliability of system components.

4.1 GUIDELINES FOR SAMPLE DELIVERY

Even though great care has been taken to ensure that points of sample extraction fulfill the objective for as-early-as-possible detection of plutonium aerosols in the workplace, the methods employed for sample intake and presentation to the detector are also critical to the effective performance of the sampling-instrument system.

Two types of sample collection systems are considered acceptable for prompt detection of airborne plutonium aerosols. One system provides for collection of particles on a filter medium that is continually "viewed" by an alpha detector. An alternative system use an annular impactor for separation of particulates into two size ranges: 1) heavier particles of plutonium and those greater than approximately 1-µm AED are impacted and held on a scintillator-coated planchet that is continuously "viewed" by a photomultiplier tube; and 2) smaller particles of <1 μm, typically associated with radon decay particles, remain entrained in the airstream as its direction is reversed by the impactor device.

Optimal performance in the sample delivery portion of these systems requires a design that

- shall minimize particle losses by various mechanisms (e.g., gravimetric settling, impaction, static charge)
- shall avoid localized or preferential areas of particulate buildup on the collecting medium
- shall eliminate air in-leakage (less than 10% of the sampling flow) between sample intake and delivery to the collecting medium
- shall resist corrosion or other possible reactions with the atmosphere sampled and facilitates decontamination.

Standard approaches to meet these guidelines are considered in the following sections.

4.1.1 Minimizing Particle Loss

In bringing the air sample to the detector, particle loss by impaction and other mechanisms can occur in two ways: 1) significant loss of particles can occur in a sample transport line to the instrument, and 2) loss can occur within the portion of the instrument where the sample is presented to the collecting medium.

When a sample transport line is necessary, losses should be minimized by meeting the following conditions:

- The transport line should be made of conductive material with a smooth interior surface.
- The transport line should be a single rigid tube with an internal diameter sized to achieve at least 0.5 m/sec (100 ft/min) linear velocity. Where it becomes necessary to use flexible tubing, a conductive surface tubing should be chosen.

- The length of the transport tube should be as short as possible, and any length greater than 6 ft should be we17 studied and justified by other overriding factors. Horizontal runs should be minimized to prevent gravimetric settling.
- The transport tube should have no more than one bend with the bend radius at least 5 tube diameters.

The arrangement of sample flow within the instrument is predetermined in the case of commercially available instruments. When choices are available for filter-type systems, preference should be given to designs that maximize the smooth flow of the sample to the collection medium. In these systems, designs should be avoided that cause abrupt directional changes in the flow path or which result in a jet-like introduction of the sample that will cause impaction and Toss of particles on the chamber walls.

4.1.2 Minimizing Sample Self-Absorption

Because the function of the air monitoring system for plutonium aerosols depends upon the detection of alpha particles, it is important to maximize the efficiency for detection of the alpha radiation. It then becomes important to have the detector view a thin, evenly dispersed collection of particles from the air sample. Pile-up of agglomerated particles, along with dust and other particulates in the work atmosphere, produces significant loss in alpha detection capability due to self-absorption affects. Frequent sample changes (daily) are strongly recommended to minimize atmospheric dust loading that could interfere with alpha counting. (See Section 4.2.4 for additional information.) Consequently, the sample flow to the collector medium should produce an evenly distributed collection of particles with approximately the same surface dimensions as the detector. Conversely, the detector should be sized to fit the desired sample dimensions in order to maximize the counting efficiency.

4.1.3 Eliminating Air In-Leakage

For filter collection systems, air leakage between the sample intake and the sample collection medium should be virtually eliminated to the greatest degree possible by instrument design. Vacuum seal mechanisms should be easy to operate and easily maintained. O-rings are generally required and should be chosen and specified for characteristics of long life and capability to retain dimension and resilience. Procedures should be employed for routine checks of air in-leakage. One of several approaches may be used:

1. The leakage may be checked by gently blocking the air inlet and observing whether any flow is indicated by the airflow meter associated with the instrument. Care must be taken because the detector and filter medium may be damaged by abrupt pressure changes.

2. The instrument may be isolated from the usual vacuum source, and a vacuum pulled on the system to a set point, with loss of vacuum noted by gage.

3. The tracer or other leak-testing techniques may be conducted per ANSI Leak Testing Standard N 14.5-1987 (ANSI 1987). Air in-leakage should be less than 10% of the nominal flow rate.

4. Rotometers may be positioned up- and downstream of the section to be tested, and the differential reading (with appropriate corrections for pressure differentia1) used as an index of in-leakage.

The second or third approaches are not amenable to testing a system in service, but should be considered for acceptance testing of new equipment and testing of equipment removed from service for calibration or repair. Some systems have a low flow alarm that will be activated by these tests and, particularly for field testing, provisions should be made to inform affected personnel of the test.

4.1.4 Minimizing Deterioration and Facilitating Decontamination Capability

Where the sample intake is separated by distance from the instrument, adherence to the foregoing standards for conductive, rigid, single-piece sample delivery tubes typically results in the choice of stainless steel for these tubes. This choice will satisfy the criteria for a delivery tube that has a long life and does not corrode or deteriorate under conditions of workplace sampling. The use of flexible plastic tubing should be avoided for reasons concerning deterioration with age and susceptibility to kinking and particle losses caused by static charge. The choice of stainless steel tubing will also facilitate decontamination of the sample delivery tube, should that become necessary.

The system and mechanisms within the instrument for sample collection also should be designed and constructed to minimize deterioration and to facilitate decontamination. The filter/collection medium holder should be easily removable for decontamination, and easy access for decontamination should be provided to the sample distribution system within the instrument and to the detector. Annular impactor devices require periodic inspection and cleaning to ensure against buildup of inert or contaminated materials.

4.2 GUIDELINES FOR SAMPLE COLLECTION

The sample collection system for rapid detection of plutonium particles in the workplace should be designed and operated to optimize various characteristics important to achieving a desired level of sensitivity. Most filter-type instruments for rapid detection of airborne plutonium use an alpha spectrometry approach to eliminate a major portion of the alpha activity contribution from natural background. Consequently, a major feature of the collection system should be to minimize the degradation of alpha particle energies within the sample itself and within the collecting medium. While less critical for impactor-type instruments, it is also important to minimize loss of alpha particles within the sample and to quantify typical collection efficiencies.

The characteristics of the sample collection system design and operation believed most important are as follows:

- The sampling rate should be an acceptable compromise between a high-volume flow to capture as large a sample as feasible and the practical limitations of physical features, collecting medium and detector size. For impactor systems the sampling rate must be maintained to achieve the size fractionation design feature.
- The physical dimensions of the collection medium should be approximately comparable to detector size and maximize particulate collection efficiency for particle sizes of interest.

- The collection medium used should minimize particle burial within the medium and present a relatively low resistance to airflow. The medium should also be amenable to other methods of analysis, when desired (e.g., it should have negligible background count contribution, present no interference to the analysis method, and be easy to process).
- The frequency of change of the sample collection medium should be guided by sample loading experience, specific workplace needs, and experience with optimal sampling periods to obtain samples containing the amount of activity for the optimal discrimination of naturally occurring activity.

The standard approaches recommended to meet these guidelines are discussed below.

4.2.1 Sample Flow Rate Considerations

Although lower levels of sensitivity in terms of DAC-h to arrive at a valid alarm level can be achieved by high-volume air sampling (sampling rates greater than 20 scfm), practical considerations usually dictate that an acceptable compromise be made. These considerations include sizing of vacuum source and supply system for central-vacuum, fixed installations, and portable units; sizing of the instrument itself; and sizing of the collecting medium in order to achieve optimal retention, prevent sample blowoff, prevent sample burial in the filter medium, and prevent deterioration of the filter medium. Experience has shown the following sample flow rates to be commonly achievable, considering the factors involved:

- for the impactor-type CAMs, a flow rate of about 40 scfm
- for 47-mm-diameter filter media, a flow rate of about 2 scfm
- for 25-mm-diameter filter media, a flow rate of about 1 scfm

For the filter medium collectors, the flow rates indicated above produce a linear velocity through the effective area of the filter in the range of 60 to 100 cm/sec.

The choice of flow rate also must consider the capability of the vacuum source for the ambient pressure conditions at the facility location. Air movers at locations appreciably above sea level will have less capability (in standard cubic feet per minute) than those at sea level.

When filter media are used, a backup support that produces negligible pressure drop shall be used behind the filter to prevent cupping and medium deterioration. The medium chosen should also be strong enough to maintain integrity at the sample flow rates and during handling before and after sampling.

4.2.2 Desired Characteristics of the Collection Medium

The collection medium used should have a high efficiency for collection of particles in the size range of interest. This size range is generally considered to be from I to 10 µm. The collection efficiency should be greater than 90%.

Typical filter pressure drop and collection efficiencies for 1-µm AED particles are shown in Table 2.

TABLE 2. Particle Collection Efficiency and Typical Pressure Drop for Selected Filter Types (Liu, Pui, and Rubow 1983)

Filter Type	Velocity, cm/sec	Pressure Drop, cm/Hg	Collection Efficiency, %
Cellulose[a]	45.2	3	94.4
	124	10	99.1
Glass Fiber	43.7	3	>99.9
	141	10	>99.99
Membrane (3-µm)	72	10	>99.99
	131	20	>99.99
Membrane (5-urn)	59	6	>99.99
	98	10	>99.99

(a) It should be noted that cellulose filters are not recommended as CAM filter media because of significant "burial" of particles in the matrix of the filter.

High pressure drop can reduce flow. Glass fiber filters show a moderate degree of pressure drop, while membrane filters show a significant pressure drop that increases with decreasing pore size. For membrane filters, a nominal pore size <1.5 μm gives a reasonable compromise between particle collection efficiency and airflow resistance.

In the impactor-type CAM, the heavier particles are collected on an optically transparent plastic planchet that is coated with ZnS (Ag) and a thin film of a silicone fluid. Collection efficiencies are found to be 90% and greater for particle sizes >0.5 μm.

To optimize the geometry affecting the counting efficiency, the collection medium size and detector size should be approximately equivalent. It is highly desirable to achieve a 2π counting efficiency from the geometric configuration of at least 10%. Greater efficiencies are highly desirable. (Counting efficiencies of approximately 40% are observed with the impactor-type CAM.) Note: In comparing count results with DAC values as in calculating the lower limit of detection, a 4π counting efficiency must be used rather than 2π.

The spacing between detector and sample should be small to minimize degradation of alpha particles by air absorption, but not so small as to adversely affect the counting efficiency and to result in particle losses created by impaction on chamber walls.

4.2.3 Burial Loss and Pressure Drop Considerations for the Collection Medium

The sample collection medium used should minimize the loss of capability to detect emitted alpha particles at or near their true energies as a result of burial of particulates in the matrix of the filter or within the mass of sample collected. Both glass fiber filters that have a random mesh of fibers and membrane filters that have a controlled pore size are commonly used for rapid detection airborne plutonium monitors. Even though the cost is greater, the use of membrane filters is recommended for filter-type sample collectors. Membrane filters offer advantages in decreased burial loss of particles, which enhances alpha spectrometry, and are more amenable to other analytical methods if that should be desired for further characterization of the sample. With proper selection of pore size in a membrane filter, it is also possible that a portion of the naturally occurring particulates, which are, typically, extremely small particles, may pass through the filter.

Although membrane filters are recommended because of their surface deposition characteristic, properly chosen glass fiber filters also efficiently collect the particle sizes of interest on the surface of the medium. Higby (1984) investigated alpha counting losses for a particular type of glass fiber filter medium (HV-LB5211). These data should be indicative of the performance to be expected from similar glass fiber filters. In general, Higby found that 10 to 15% of alpha particles from PuO_2 aerosols were lost for counting by burial within the medium; loss of alpha particle resolution was in the order of 2%. His investigation included particle sizes ranging from 0.66 to 3.07 μm at linear sample velocities ranging from 50 to 200 cm/sec. His study confirmed that glass fiber filters tend to be surface collectors, particularly for particle sizes larger than 1 μm at linear velocities typical for filter-type CAMs. From these data it appears that burial of particles should be considered but is not a major source of error when carefully chosen glass fiber filters are used for the CAM sample collection medium.

For the impactor-type CAMs, an annular deposition of particles occurs on the surface of the silicone fluid-covered scintillation material. This is primarily a surface collection phenomenon; however, excessive use of coating fluid and excessive buildup of the sample deposit can cause a significant loss of alpha particles by absorption. These factors must be controlled.

4.2.4 Frequency of Sample Change

The frequency of sample changing for rapid detection monitors shall be determined by considering needs and limitations of the workplace. The rationale for sample change frequency shall be well thought-out and documented. The establishment of a sample change frequency should consider:

- minimizing the atmospheric dust loading on the sample
- establishing an acceptable "routine" for servicing and inspection of the instruments
- establishing a special surveillance schedule for high risk potential work phases

- establishing a new baseline after an alarm and when controlling or corrective actions have been taken
- providing a schedule to accommodate special needs per work shift or per operational phase.

It is recommended that the collection medium be changed at least once a week. Daily changes are strongly advised to minimize atmospheric dust loading on the collector.

4.3 AIR FLOW CONTROL AND MEASUREMENT REQUIREMENTS

Each instrument for rapid detection monitoring of plutonium aerosols should be equipped with a reliable airflow rate measuring device. In addition, the flow rate should be adjustable at or very near the instrument. While accuracy in the airflow rate measurement is not extremely important for rapid detection instruments, the nominal airflow rate should be the minimum value throughout the period of sampling. It is recommended that higher flow rates be no greater than 20% of the nominal value.

Maintenance of flow rate can be provided by flow control devices that adjust flow rate to compensate for filter loading. Because excessive filter loading is detrimental to particle detection and the alpha spectrometry feature employed by most CAMs, it is preferable to maintain a periodic (once per shift or once per day) surveillance of instrument status, including the airflow rate. Cases of rapid and significant loss of flow rate should indicate the need for increased frequency of sample collector change.

Most commercially available CAMs are provided with simple rotometers for measurement of airflow. The rotometer is a variable diameter tube containing an indicator float. The aerodynamic forces of the airflow within the tube raise the float to a level proportional to the airflow. The accuracy of the rotometer is affected by the degree of internal cleanliness and variations in nonstandard conditions for the air flowing through the tube, e.g., pressure and temperature. A new rotometer can be expected to be more accurate than one that has been in service for some time. Recalibration of CAM rotometers should be performed at least annually, with corrections made for conditions of actual use. (Note that the rotometer in this use is operating in a system at less than atmospheric pressure.) It is highly recommended that initial and recalibrations be performed using a mass flow meter with its calibration traceable to a National Bureau of Standards (NBS) standard. These devices use a measurement of heat dissipation to measure airflow, are more accurate than rotometers, and offer negligible pressure drop in the system. The indicated flow rate is for "standard" conditions of temperature and pressure.

It is recommended that, when feasible, consideration be given to use of mass flow meter devices for measurement of airflow at the instrument. Tn some applications, a mass flow meter may be considered susceptible to breakage under field operation or calibration conditions. In those cases it is recommended that the field calibration device be bench-calibrated with a mass flow meter.

4.4 VACUUM SOURCE AND SYSTEM BACKUP REQUIREMENTS

A reliable source of vacuum with adequate reserve capacity is necessary for individual or multiple CAM systems. Single or portable instruments should be equipped with a positive displacement vacuum pump with adequate and reserve capacity to provide the desired airflow rate. As indicated earlier, facilities at higher elevations will require added pump capacity to provide the desired sampling rate. The vacuum pump should not overload at the desired sampling rate and should be powered by 110 V (ac). Multiple, fixed-unit CAM systems should be hard-piped and manifolded to a central vacuum source with adequate and reserve capacity to provide the desired sampling rate for all monitor instruments. Care must be taken in the design of the manifolding and pipe run system to provide adequate sampling capacity at remote points in the system. Individual or central air movers should be equipped with a low flow rate alarm signalled to an appropriate location for response actions.

It is highly recommended that a central source of vacuum be backed up by a redundant spare unit to eliminate the possibility of system downtime for repair. Any major system downtime could result in curtailment of operations in the facility.

Although somewhat controversial, consideration should be given to the need for a supply of emergency power to fixed instruments and to their source of vacuum. It is usual practice that operating personnel evacuate their work areas when a loss of electrical power occurs. Thus, the need for further warning capability may not be necessary. On re-entry, however, it may be beneficial to know whether aerosol releases have occurred in the interim. If emergency power cannot be supplied to all instruments, consideration should be given to providing that capability for instruments in representative and/or high-risk locations.

4.5 RELIABILITY OF SYSTEM COMPONENTS

The reliability of the components of the sample delivery and collection system, and their interactions, are just as important as the reliability of the instrument portion of the total rapid detection system. These components shall be designed, maintained, and calibrated to reproduce their functions over a long period of time and under varied environmental conditions.

4.5.1 Specifications

The specifications for sample delivery and collecting system components should be developed with care and engineering input whether procurement is from commercial vendors or from in-house sources. Specifications should ensure, as applicable, that:

- Item will be user- and maintenance-friendly.
- Construction material and surface finishes will resist corrosion, minimize particle losses, and sustain decontamination.
- Components can be made accessible for inspection, maintenance, and cleaning.
- Collection medium will collect particle sizes of interest with high efficiency and minimal self-absorption effects, concomitant with acceptable pressure drop.
- The system will have negligible in-leakage of air.
- Airflow measurement devices will present no ambiguity in readout, show adequate sensitivity, and give continued reproducible service over a long time period.

- Air movers will maintain adequate capacity plus reserve over a long time period. Their noise levels should be within acceptable limits.
- Emergency power will be supplied to central vacuum sources or to selected individual units.

4.5.2 Acceptance Testing

New equipment should be subjected to acceptance testing against specifications, at least on a statistical basis. Although acceptance testing of filter media is not generally feasible, equipment should be procured from a reputable vendor and visually inspected for mechanical defects. Where possible, sample collection efficiencies should be locally verified.

4.5.3 Inspections

Periodic inspections are vital to maintaining reliability in operation for most components of the sample delivery and collection system. Periodic inspections should include:

- condition of sample transport lines (e.g., cleanliness, deterioration, blockage, water)
- condition of O-rings and seals
- tests for air in-leakage
- detector and sample collection chamber contamination and cleanliness
- cleanliness of airflow meters
- loading experience for collectors (excessive loading indicates need for more frequent sample change)
- mechanical performance of air movers.

4.5.4 Maintenance and Calibration

A formal program for maintenance and calibration of sample delivery and collection components should be integrated into the instrument maintenance and calibration program. A high priority for repair and maintenance must be established for these components. Particular attention should be given to the periodic, documented calibration of airflow measurement devices.

5.0 INSTRUMENT SPECIFICATIONS FOR EFFECTIVE EARLY DETECTION OF AIRBORNE PLUTONIUM IN THE WORKPLACE

The measurement instrumentation quantifies the amount of airborne plutonium present. If the other components of the prompt detection system operate properly, a well-chosen, well-calibrated, and well-maintained instrument will provide the correct airborne plutonium concentration and activate the alarms at the proper times.

The various factors that should be considered to obtain a reliable instrument for the measurement of airborne plutonium are discussed in this chapter, along with the impact of some of the characteristics of other components of the system on instrument performance. The information in this chapter is included to emphasize the interrelationship of all components of the system for proper operation of the entire system. The lower limit of detection and the performance characteristics of detectors and filters are discussed in Sections 5.1 and 5.2, respectively. Reliability criteria are given in Section 5.3. Section 5.4 provides details on good practices of maintenance and calibration. Finally, Section 5.5 covers the characteristics of commonly used plutonium air-sampling instruments.

5.1 LOWER LIMIT OF DETECTION

The primary purpose of any CAM is to detect the presence of airborne radioactivity and activate an alarm to warn personnel in the area so that actions can be taken to minimize personnel exposures (ANSI N317-1980). The lower limit of detection for prompt detection systems shall be 8 DAC-h, averaged over any time period exceeding 1 min. With this purpose in mind, the goal for any CAM should be to perform this function as quickly as possible and at the lowest detectable level of the radioactivity of concern. The quantity of airborne radioactivity that will result in an alarm within a given time interval is defined in units of DAC-h for a particular radionuclide and is a function of the nuclide's airborne concentration in DACs, the sampling rate, the lower limit of detection for the instrument, and the time needed for the alarm to occur. The lower limit of detection may be affected, however, by spurious alarms caused by interference from natural airborne radioactivity, an electromagnetic field or line perturbations, or other factors. If excessive spurious alarms occur, prompt responsive action by personnel will decrease and the CAMs will not serve their intended purpose. Therefore, optimization of a CAM involves providing the detection of the lowest possible level of collected radioactivity in the shortest possible time while simultaneously ensuring that spurious alarms are minimized to an acceptable level. The acceptable level of spurious alarms is arbitrary and subjective and depends upon such factors as the specific use of the instrument and the number of total instruments at a facility.

5.2 DETECTION AND FILTER CHARACTERISTICS

A number of different factors affect the level of radioactivity that will be detected by an instrument in a given amount of time and the probability of experiencing spurious alarms. Besides the volume and rate of air sampled (already covered in Section 4.2.1), major factors include 1) efficiency of the radiation detector and sampling unit; 2) methodology for radiation discrimination and natural airborne radioactivity compensation; 3) methodology for alarming the instrument; 4) shielding for extraneous sources of interference; and 5) mechanical/electrical reliability and ruggedness. These factors are discussed below.

5.2.1 Efficiency of the Radiation Detector and Sampling Unit

The efficiency of the detector is related to the inherent detector sensitivity, the geometry of the detector in relation to the filter medium or sample chamber, and the characteristics of the filter and unit operation. These characteristics include burial of radioactivity in the filter, attenuation due to dust loading, and self-attenuation. Consideration shall be given to each of these factors to maximize the detection of radioactivity upon the filter.

Most modern, commercially available alpha-continuous air monitors employ solid-state surface barrier and/or diffused-junction detectors, with the latter type being generally preferred because of their better durability in harsh environments. These detectors typically exhibit an inherent efficiency for alpha-particle detection in the range of 8 to 30% (2π geometry), depending upon the commercial manufacturer, with degradation of the efficiency resulting with prolonged use. Ten percent should be considered to be the lower acceptable efficiency limit for this type of detector. The size of the detector is also important. Because of cost limitations, the detectors in most commercially available CAMs are about 500 mm^2; however, as costs decrease, the use of larger detectors, approximately 2000 mm^2, may soon become preferable to the smaller ones. The sample diameter should approximate the detector diameter to avoid losses in detection efficiency.

The distance of the filter from the detector is another important factor for alpha CAMs. Scattering and energy degradation of the alpha particles by burial in the filter medium and in the intervening air produce in both decreased detector efficiency and poor spectral resolution for spectroscopy instruments. Therefore, this distance shall be minimized as much as possible to reduce these effects. The distance is approximately 1/8 in. for most commercially available instruments; however, some manufacturers indicate that distances up to 3/8 in. can be utilized with minimal degradation of energies. A good instrument maintenance and adjustment program is necessary to maintain these distances over prolonged time periods.

A few noncommercial CAMs provide an evacuated chamber to minimize air intervention effects. Unfortunately, the reliability of these instruments tends to suffer from increased mechanical complexity. Also, the response time of the instrument lengthens due to having to evacuate the chamber before counting collected activity on a filter.

5.2.2 Methodology for Radiation Discrimination and Natural Radioactivity Compensation

The next factor to be discussed, as related to CAM detection capabilities, is the technique used for discriminating against natural airborne radioactivity. The major problem affecting CAMs used for detection of plutonium and other transuranic alpha-emitting nuclides is the presence of natural background radiations from radon-thoron daughters. The ^{222}Rn granddaughter, ^{218}Po, has a 6.0-MeV alpha particle emission; radon-220 eventually decays to ^{212}Bi with a 6.05-MeV alpha particle emission. The degradation of these alpha particles by filter imbedding and intervening air between filter and detector results in 5- to 6-MeV energies similar to those of the nuclides that one desires to detect. Figure 3 illustrates the overlap of these naturally occurring isotopes with ^{239}Pu settings for most instruments (Cucchiara, Stafford, and McAtes 1983). Because the level of ^{218}Po and ^{212}Bi present in a work area can fluctuate drastically with ambient atmospheric ccnditions, workplace ventilation rates, facility construction material, and temperature, interference from the nuclide is highly unpredictable and shall be compensated against to minimize spurious alarms while allowing a reasonably low alarm setting. Setting the window width of the background to 1 MeV, with the threshold riding on the upper plutonium window setting, reduces interference from the highly variable RaC' (^{218}Po). Additionally, correct setting of the background subtract percentage also reduces this interference.

The early commercial CAMs provided little or no compensation against ^{218}Po and ^{212}Bi alpha interference, and such units should be used only for closely supervised short-term operations to preclude interference problems. Later CAMs have become more sophisticated and typically employ a single-channel analyzer (SCA) dedicated to measuring the ^{218}Po and ^{212}Bi level. A

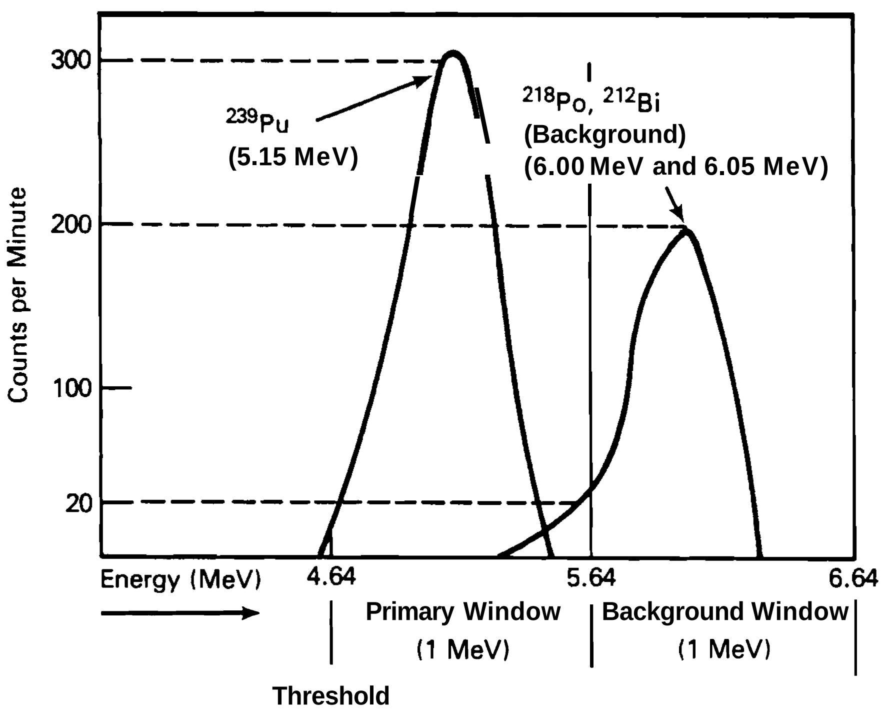

FIGURE 3. ^{239}Pu and Background Alpha Particle Energies as They Relate to Typical CAM Settings for a Plutonium Work Area

constant fraction of the alpha particle detected by this SCA is then assumed to cause interference in the primary measurement region for plutonium and is electronically subtracted out of this latter region. Although the scheme is much improved compared to CAMs without compensation, it suffers from the fact that the ^{218}Po and ^{212}Bi interference into the primary region of interest is not truly a constant fraction. Rather, the interference tends to decrease with the length of time the unit is in operation, probably as a result of decreased filter burial as dust loading increases.

With the compensation scheme discussed above, typical commercially available CAMs should be able to detect at least 7.5 to 10 DAC-h of ^{239}Pu at a typical sampling rate of 2 ft^3/min. Under these conditions, such instruments should be able to operate 24 h/day with an acceptable low false alarm rate caused by ^{218}Po and ^{212}Bi interference. The units could also be run for short time periods with lower alarm settings and resultant improved detection. Increasing the airflow rate, the detector size, or the detector efficiency will also proportionally reduce the detection level.

5.2.3 Methodology for Activating the CAM Alarm

Microprocessor-based CAMs will also allow for future improvements to be made in determining when a CAM activates an alarm. Present units usually have a single high-level adjustable set point. This alarm setting should be high enough to minimize spurious alarms originating from fluctuations in natural airborne radioactivity. A major disadvantage to this relatively high alarm point setting is the increase in time required to detect a low-level release of radioactivity. With a detection capability of 20 DAC-h, the instrument must operate for 20 h at a 1 DAC level to detect a 1-DAC release level. Another disadvantage of a single-point trip alarm is the inability to avoid alarms resulting from rapid temporary perturbations, such as are typically caused by extraneous electromagnetic or electrical interference.

Microprocessor-based CAMs under development will allow for software programming that will mitigate both of the above problems. For example, the unit can be programmed to provide an alarm when the detection limit exceeds a pre-established statistical limit based on the recent counting history, allowing for a quicker response to slow releases. To minimize false alarms caused by transient spikes from extraneous interference, the CAM can be programmed to alarm only when a high-level trip point is exceeded for a pre-established sustained time interval. These improvements in alarm methodology, along with the improved ^{218}Po and ^{212}Bi compensation, should allow the new generation of microprocessor-based CAMs to reliably detect transuranic airborne radioactivity at 4 DAC-h or lower. Alarms have also been improved to incorporate a variable frequency to avoid differences in alarms from other laboratory instruments. It also allows those individuals who have specific hearing frequency deficiencies to detect the CAM alarm.

5.2.4 Shielding for Extraneous Sources of Interference

Several extraneous sources can affect the reliability of CAMs. These major extraneous sources are large amounts of beta, gamma, or neutron radiation, radiofrequency (RF) interference, temperature, and vibration. CAMs should be appropriately shielded or inherently designed to detect only alpha radiations in the presence of other potential ambient radiation sources. Many commercial CAM manufacturers incorporate a RF shield around the solid state detector, which is relatively effective in low-RF environments. Tn higher RF fields a Faraday Cage around the instrument may be required. Most commercial CAMs operate adequately under normal ambient laboratory and environmental temperatures. However, when temperature variations fall below 0°F or above 110°F, special instrument design characteristics must be incorporated. If these excessive constraints are possible, they should be clearly identified in the instrument design specifications. Additionally, unusual vibration or acceleration characteristics of the instruments' environment should be incorporated in the procurement specifications. Most manufacturers have the capability to test and certify instruments to meet variable vibration frequency environments.

5.2.5 Mechanical/Electrical Reliability and Ruggedness

The following are examples of specifications that may be included to ensure mechanical/electrical reliability and ruggedness.

5.2.5.1 Detector Type

The detector should be environmentally sealed. It should also be cleanable and resistant to corrosive environments such as 2M HNO_3 vapors. (See also Section 4.5.)

5.2.5.2 Location of the Detector and Filter Assembly

When the detector and filter assembly is mounted on the mainframe electronics, no external cable shall be required. The detector/filter assembly should have a connector capable of mating directly with another connector on the housing of the mainframe electronics enclosure. This assembly should be capable of being remotely located a minimum of 10 ft (up to 75 ft) from the mainframe electronics by the use of an optional extension cable. Removal of the detector and filter assembly from the mainframe electronics should not require specialized knowledge or tools.

5.2.5.3 Remote Reading

The capability of remotely measuring or determining the magnitude of airborne release should be provided. This allows for appropriate determination of required re-entry personnel protection equipment and knowledge of the level of a continuing release of airborne material. Appropriate historical data retrieval should provide an activity time sequence. Examples of such data retrieval would be instrument memory storage, computer data storage, or a recorder.

5.2.5.4 Emergency Electrical Power Requirements

If continuous air sampling is required during electrical power losses at a facility, provisions should be made for alternative electrical power. Usually, selected instruments in strategic locations can receive their electrical power from an uninterrupted power supply such as batteries or fuel-powered generators. This would require that power be received by both the air sampling instrument and the vacuum source.

5.2.5.5 Detector Limits

At least 8 DAC-h or less of ^{239}Pu should be detected with a variable radon-thoron background of up to 800 dpm within the range of 4.4 to 6.5 MeV, and with an airflow of 28 L/min (1 ft^3/min) at a specific altitude.

5.2.5.6 Range of Measurement

The instrument shall be capable of measuring at least 10,000 cpm with overrange indication.

5.3 SYSTEM RELIABILITY

The main driving force behind a reliable early warning system should be the rapid detection of airborne plutonium that has the potential for personnel exposure in the workplace. A truly reliable monitoring system provides consistent responses to plutonium activity, with primary emphasis on the precision rather than the accuracy of measurement. Instrumentation must consistently detect and alarm at the lower level of detection of plutonium airborne concentration. Early warning monitors must be capable of providing the maximum number of true alarms while minimizing the number of spurious or false alarms (less than 10%). This capacity is probably the single most important facet in developing worker reliance on and respect for the system that is intended to warn them of potential airborne plutonium radioactivity.

In addition to being able to withstand the rigors of constant use and everyday demand, early warning instrumentation for plutonium must be capable of withstanding abnormally harsh environmental conditions that are often associated with processing and fabricating plutonium, such as high temperatures, chemicals, caustics, and acids. Early warning monitors should be relatively "trouble-free" for the first few years of service and provide reliable field operation with a minimum number of major repairs over a reasonable instrument lifetime of at least 5 years. A reliable early warning system for plutonium can only be achieved with aggressive and comprehensive calibration and maintenance programs, which are discussed below.

5.4 MAINTENANCE AND CALIBRATION

Consistent maintenance and calibration of CAMs are of primary importance in reliable detection and alarm capabilities. This section discusses general practices to ensure this reliability.

5.4.1 General Maintenance and Acceptance Criteria

CAM maintenance and calibration programs shall be developed and organized to provide a warning system with a demonstrated record of high reliability in field operation. These programs must address both the electrical and mechanical aspects of instrument operation.

Electrical maintenance should minimally include a check of the following:

- detector
- electronic circuitry
- alarm circuitry
- instrument failure indicators
- power supply (system connected to UPS)
- computer/remote interface
- background subtraction
- instrument efficiency/counting circuitry
- periodic performance testing at two points across decades of range, per ANSI N323 (1978).

Mechanical maintenance should minimally be performed for:

- recording device
- flow rate optimization, by cleaning and replacing necessary components on regular schedule
- flow rate calibration
- in-leakage testing
- instrument decontamination.

Periodic performance testing and calibration shall be conducted in accordance with ANSI N323-1978, at least annually, at two points across the range of detectability, using NBS traceable sources. Adequate documentation shall be maintained to allow verification that the action is being accomplished.

More routine operability source checks should be performed at one point to verify alarming capability and ensure proper operation. It is recommended that this be performed weekly with formal documentation of the source check. The sources should be checked monthly to ensure no loss of activity.

Maintenance and calibration programs should begin with the receipt inspection and acceptance testing of a random sampling of new equipment against purchase specifications provided to the vendor.

Extensive documentation and quality assurance programs are needed throughout the lifetime of an instrument, beginning with the initial receipt inspection and calibration. These programs are needed to ensure day-to-day reliable functioning of the early warning system. Development of an instrument data base for each instrument provides a maintenance history that allows performance tracking of reliability, high maintenance items, and excessive false alarms, and provides a basis for future purchases.

5.4.2 Calibration and Performance Checks

Radiation check sources used to check the instrument should be calibrated monthly; an NBS traceable source shall be used as an annual check. The individual checking the instrument should place his or her initials and the time and date of the filter change on the chart paper or the sticker attached to the instrument. When providing maintenance and changing the filter, care should be taken not to touch the sensitive surface of the solid state alpha detector.

CAMs shall be monitored on a routine schedule to check for proper operation and to check the counter efficiency. Before doing the calibration check, ensure that all CAM settings are correct. Suggested settings (LANL 1987) for the plutonium workplace should be:

- plutonium window (SCA #1) - 1.0 MeV
- threshold - 4.65 MeV
- background window (SCA #2) - 1.0 MeV
- response (if present) - Slow
- mode - PHA-SUB
- range (if present) - x1

  alarm setting: - 20 to 40 cpm.

The settings used for natural activity discrimination shall be justified and the rationale documented. It should be noted that the window and threshold settings given above are for plutonium areas and are satisfactory for detecting the presence of ^{242}Pu, ^{239}Pu, ^{238}Pu, ^{241}Am, and most other plutonium isotopes. However, the settings would have to be changed for the detection of other alpha-emitting isotopes with primary alpha energies below 4.64 MeV or above 5.64 MeV, such as ^{235}U

Only someone thoroughly knowledgeable in the theory and operation of the CAMs should make adjustments in the settings.

After verifying that the settings are correct, perform the alpha air-sampling instrument calibration using the following steps, which are typical of most CAMs:

1. On a CAM calibration sheet, record the window setting, threshold setting, calibration source number, source strength in dpm, and expected source count rate in cpm.
2. For each CAM calibrated, record the date, location, and CAM number.
3. Turn off the vacuum pump and remove the sampling filter.
4. Insert a calibrated ^{239}Pu standard source.
5. Observe that the CAM will alarm on the x1 range and record the average cpm of the alarm.
6. Allow 5 to 10 min for the CAM to obtain its maximum reading, switching ranges as necessary.
7. Record the maximum cpm in the "source cpm" column.
8. Remove the plutonium standard calibration source and instal1 a new sampling filter.
9. Turn the vacuum pump back on and adjust the flow rate to the required flow rate. Check this with a calibrated secondary flow measuring device.
10. Place the range switch in a x1 position and push the reset button. Observe that the chart recorder or meter reads approximately zero with the reset button depressed.
11. Record the date, time, and individual's initials on the chart recorder if one is being used.
12. Initial the CAM calibration sheet and record the flow meter reading.

Field checks to ensure proper response in the background window (SCA #2), if it is available on the instrument, can be rapidly performed using a ^{252}Cf electroplated source. Californium-252 alpha energies closely approximate the energies of ^{218}Po and ^{212}Bi (Cucchiara, Stafford, and McAtee 1983). The ^{252}Cf source also allows an appropriate check of the background subtract setting for those alpha energies being scattered back to the primary plutonium window.

5.5 COMMONLY USED PLUTONIUM AIR SAMPLING INSTRUMENTS

Information on some, but not necessarily all, types of commonly used plutonium air sampling and monitoring instruments is provided below, primarily for those users unfamiliar with the topic. Some specific types of instruments are discussed as examples but are not endorsed as being applicable to all situations requiring prompt detection. The types of instruments covered are silicon-diffused, junction-type CAMs; impactor-type CAMs; moving-filter type air sampling instruments; and fixed-head samplers. Although not a monitor, the portable fixed-head air sampler is used for sampling in many plutonium facilities and could be used, with good judgement, as a quantitative prompt detector in some limited situations.

5.5.1 Silicon-Diffused Junction-Type CAM

There are several commercial manufacturers who provide the plutonium CAMs, utilizing a solid-state, silicon-diffused, junction-type detector. The detectors and sampling filter may vary in size.. Most instruments incorporate two single-channel, pulse-height analyzers. Resolution of the CAM is highly dependent on the type of filter medium used to collect the air sample. For best results a membrane filter or a thin glass fiber filter is recommended. Figure 4 illustrates one such instrument that is commonly used at Los Alamos National Laboratory. Usually, detection and alarm capabilities are incorporated into the instrument. Some manufacturers also provide individual outputs from the instrument meter or pulse output from each single-channel analyzer to accommodate remote reading and analysis capabilities. These instruments may be either in a fixed location or placed on a mobile cart to be moved to the work site, as shown in Figure 5.

5.5.2 Impactor-Type CAM

The impactor-type CAM is usually set at a high volume (35 to 45 scfm) and can be used in both a fixed and portable mode. This instrument, a portable

FIGURE 4. The TA-55 CAM, Used Only at the Los Alamos National Laboratory Plutonium Facility

version of which is shown in Figure 6, has been used as an effective prompt warning device for a number of years at a DOE facility. These systems have an alarm threshold approaching 1 DAC-h (Alexander 1964). The features that allow this low level of detection include:

- high sample rate - normally 40 scfm
- good collection efficiency - 90% for plutonium >0.5 μm
- minimal radon-thoron collection efficiency - 5 to 10%
- scintillation detection efficiency - 40%
- proper setting of alarms above background levels.

The detection efficiency is reduced when dust loading of the scintillation planchet collector occurs or if the annular impaction becomes partially clogged with dust or lint.

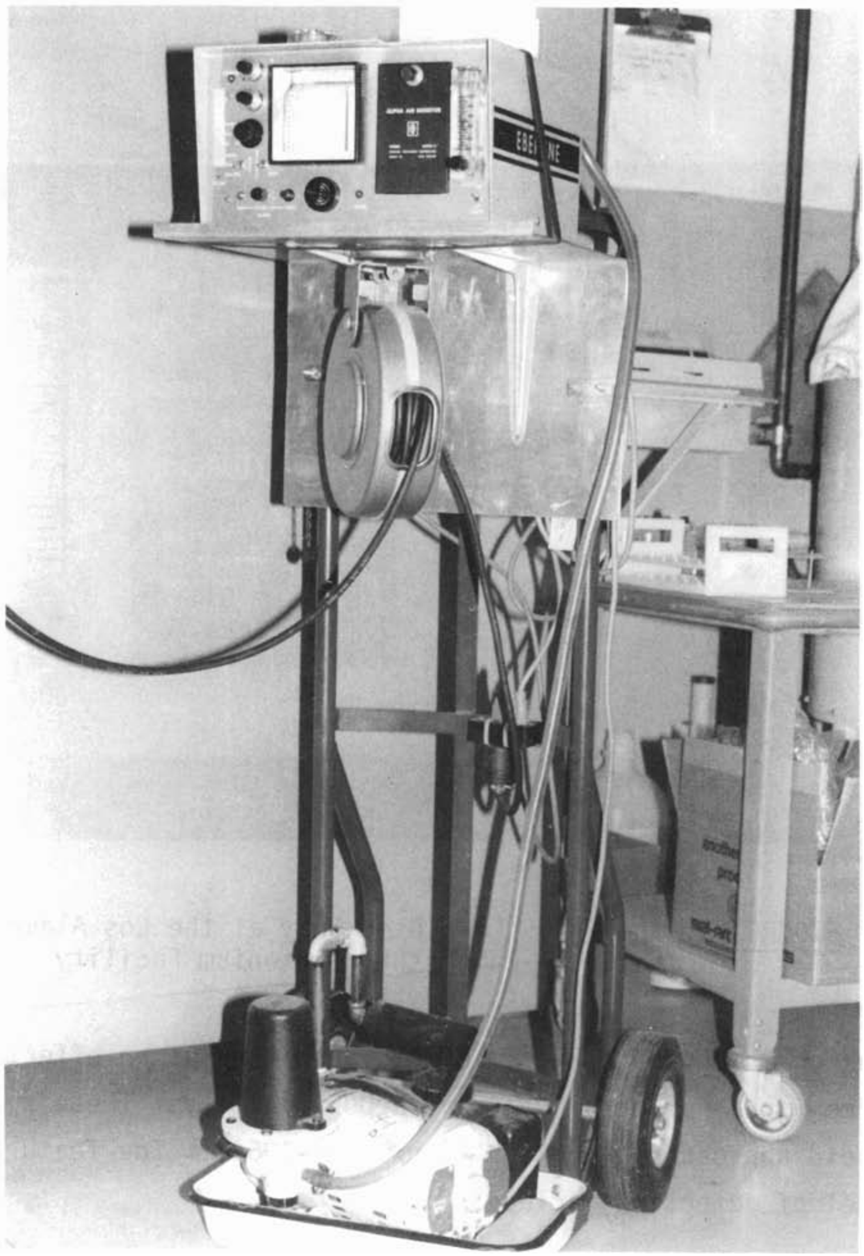

FIGURE 5. A Mobile Continuous Air Monitor (CAM) Used to Alert Workers to Airborne Radioactive Contamination in the Work Area

The distance between the detector (photomultiplier tube) and the collection is normally 1/8 in., which is close enough for efficient detection but far enough away to prevent damage to the photomultiplier tube by contacting the planchet or impactor head. Note that the instrument is considerably larger than those previously described.

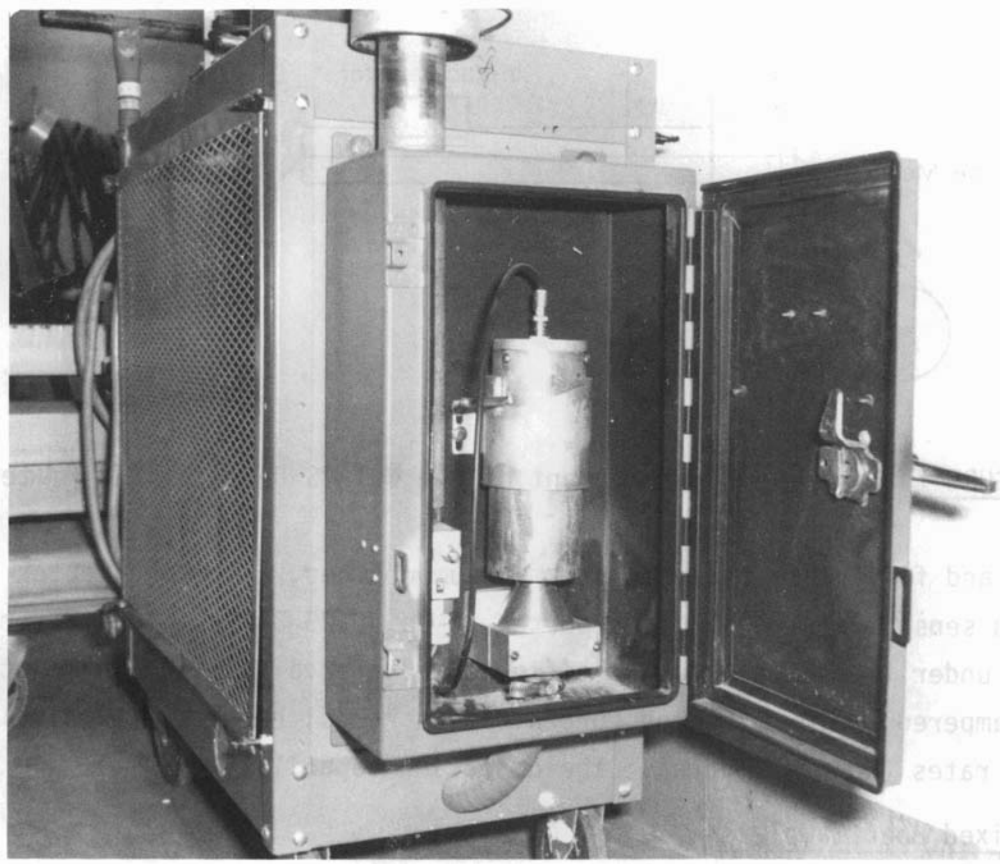

FIGURE 6. Portable Impactor-Type Alpha CAM with Light-Tight Box Door Open

When used as a fixed monitor with a central vacuum system, the light-tight box collector-detector housing is installed outside the area being monitored for easy access. The only portion of the monitor in the room itself is the sample probe and exposed portion of the delivery line as well as local audio-visual alarms. The readout units (count rate meters) and recorders can be placed at a remote location.

5.5.3 Moving-Filter Air Sampling Instrument

Several types of moving-filter air sampling instruments are available commercially and have been used for a number of years. One system called the WOTAMS was developed at Lawrence Livermore National Laboratory (Kai fer, Prevo, and Phelps 1987). Figure 7 illustrates the design of this instrument. The

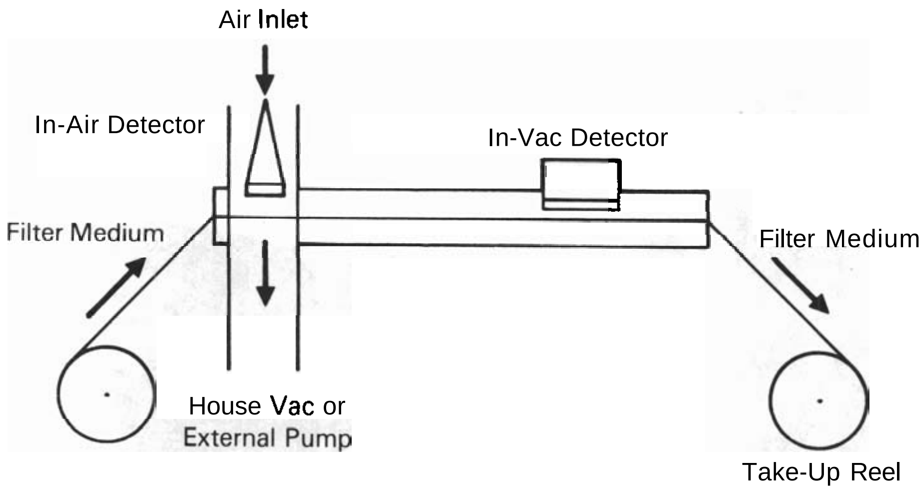

FIGURE 7. Transport Arrangement of the WOTAMS Detector and Filter

detector and filter are enclosed in a vacuum chamber, allowing greater detection sensitivity, which is reported to be <0.25 DAC-h. The filter advances under the detector at specified time intervals. Counting statistics can be hampered at low airborne concentration rates; however, relatively high sampling rates (20 cfm) increase the detection capability.

5.5.4 Fixed Head Samplers

A number of types of fixed head air samplers used in plutonium laboratories are mentioned only because they are universally used. These are collection devices and must be changed at specified time intervals and counted, usually in a remote counting laboratory. Their primary use is for engineering and housekeeping controls. Figure 8 shows a typical sampling head used in glove-box laboratories. The plastic heads house interchangeable high-efficiency filters, usually in a glass fiber filter medium. Sampling flow rates frequently exceed 2 cfm. Figure 9 shows a portable air sampling device, commonly called a "giraffe," which can be moved to a specific work location (Valentine, Meyer, and Romero 1968). This incorporates the same filter and filter-holding assembly as that just described. Again, the filter must be counted at a remote counting laboratory.

FIGURE 8. Fixed Head Air Sampling Lines in Position Above a Glove Box

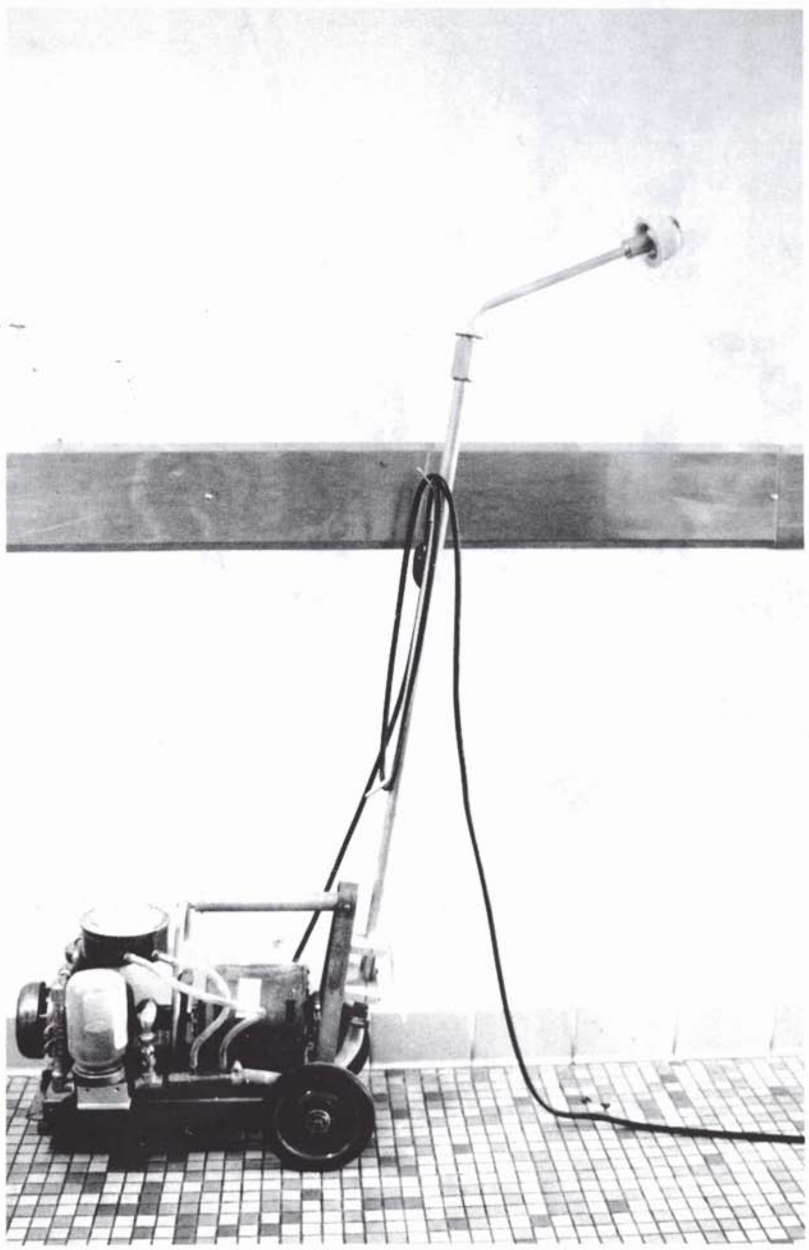

FIGURE 9. A "Giraffe" Portable Air Sampler

6.0 DOCUMENTATION

Documentation of a program for the prompt detection of airborne plutonium in the workplace is needed for a variety of reasons. The underlying purpose for documentation is to provide a basis for evaluating the performance of the program, both in internal and external program reviews. Regardless of the reasons for conducting a review, the documentation shall meet certain minimum requirements for completeness and reliability. Additional requirements may be imposed by regulatory standards or by a perceived need for additional documentation for legal purposes.

6.1 GENERAL DOCUMENTATION FORMAT, CONTENT, AND RETENTION

All records shall meet the requirements listed below.

- Air sampling records shall include reference to approved operating procedures, including identification by procedure number, revision and modification number, date, title, and author. This requirement applies to all procedures used in the location, calibration, and operation of any sampling and analytical equipment that is incorporated in the prompt plutonium detection monitor.
- Written records shall be legible. Current written records shall be prepared in black ink or typed. Errors should be lined out with a single line, allowing the original entry to be read; the corrections should be initialed by the person preparing the revision.
- Records shall be retrievable. Current files should be retrievable within a day; permanent files should be accessible such that a specific record can be provided within 1 week.
- If magnetic storage media are used for short- or long-term record storage, backup copies of the records should be made and updated on a regular basis. Long-term storage in other than written format shall take into account the expected lifetime of the storage medium. A hard (printed) copy of records should be generated whenever

possible. Written records, including any field notes, shall be retained for 30 years.

- If the rapid detection system information may be used for legal purposes (e.g., analysis of the collected material by radiochemistry following an incident), sample custody procedures shall be developed to document the transfer of the sample from its removal from the collection device through the entire analytical procedure. Sample custody should not be required on a routine basis for the samples collected in the system unless these samples are also used to estimate the long-term average concentrations in the area.
- Current records should be retained for 1 year from the collection date, and then transferred to the permanent records.

6.2 DOCUMENTATION OF SAMPLER INLET PLACEMENT STUDIES

Placement of sampler inlets will be an important factor determining the effectiveness of the rapid detection system. Optimal placement of the inlets will require knowledge of airflow patterns and assumptions regarding the transportability of contamination. The characterization of room airflows and assumptions regarding particle transport should be documented. These factors are discussed below.

- Airflow Characterization - A copy of the ventilation system drawings should be marked at the time of airflow characterization to document inlet and outlet flows and diffuser orientations at that time. In addition, any factors having a significant effect on the bouyancy of the inlet (makeup) air should be noted at the time of characterization.
- Transportability of Particles - Any assumptions regarding the anticipated transportability of contamination particles, including particle size distribution parameters, should be documented. The basis for these assumptions (experience, process characteristics, and theoretical considerations) should also be documented.
- Facility Design and Construction - In cases where a new facility is to be designed and constructed, conformance to design should be

documented. This does not relieve the facility operator of the responsibility for room airflow characterization, but will help ensure that compromises in rapid detection system performance are not inadvertently built in during the construction process.

- Inlet Placement with Respect to Other Standards/Evaluation of Requirements - If DOE system-wide, field-office, or contractor standards call for placement of rapid alarm systems depending on workplace conditions (such as surface contamination levels, maximum release potential, airflow conditions), then the studies or measurements conducted to determine these conditions should be documented.

6.3 DOCUMENTATION OF SAMPLER DESIGN, SELECTION CRITERIA, AND HARDWARE

The sampling system counting hardware will most likely be one of a few standard varieties, considering the difficulty of providing a design to meet the sensitivity requirements for the rapid detection of airborne plutonium. Sample transport lines and filter housing designs may vary, depending on the facility.

- Sample Line and Filter Housing - The geometry and spatial orientation of the sample line and filter housing as installed should be documented. Required tests of particle transport through the line and filter housing should also be documented.
- Numbering Rapid Detection Systems - In addition, each rapid detection device should be identified by a unique number, and, as appropriate, numbers should be assigned to subsystems or components identifying each as part of a system.
- Selection Criteria - As appropriate, the selection criteria or design objectives for acquisition or development of a sampling system should be documented. This applies both to systems and critical components of a system.

6.4 DOCUMENTATION OF RAW AND ANALYZED DATA

The processing of raw and analyzed data from the rapid detection system should be documented. These data include:

- any data analysis performed in the sampler beyond that required to generate a net plutonium activity signal (shown with a flow chart indicating the steps in data processing), and
- alarm and alert setting determinations.

6.5 DOCUMENTATION OF EQUIPMENT CALIBRATION AND FIELD RESPONSE ADJUSTMENTS

Flow should be maintained within the acceptable range stated in Section 4. The frequency of calibration of the sampling system flow should be determined by developing a history of performance for the air mover, or based on previous experience with the air mover. All laboratory (out-of-field) calibrations and field flow adjustments should be performed according to written procedures. Dates of flow calibration or field flow adjustments and names of personnel conducting the calibration/adjustments should be recorded.

Detection system response tests and calibration performance should also be documented. Information should include procedure number; identification of the detection system being tested; any electronics, hardware or materials used in quantifying the detection system response for the calibration; date of test; and name of personnel conducting the calibration. Numerical results of the testing should be documented.

6.6 DOCUMENTATION OF CHANGES IN THE SAMPLING SYSTEM OR WORK ENVIRONMENT

Both the sampling system and the room airflow characteristics are important in determining the effectiveness of the rapid detection system as described in this document. Changes in either may affect the system performance, so significant changes should be documented.

Changes to the sampling system that require documentation include, but are not limited to, 1) sample flow rate, 2) filter size, 3) sample line or filter housing modifications, and 4) changes in siting of a particular sampling system.

Any changes to the room that affect airflow characteristics require documentation. The acceptability of system performance in the altered airflow condition should be determined.

Periodic review of the actual versus the documented room and sampling system configuration is required and should be documented. Deviations of the actual from the documented designs should be evaluated for significant effects on the performance of the system.

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